A HANDY BOOK OF METEOROLOGY

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CONTENTS.

LIST OF CHARTS.

ERRATUM.

In paragraph 78, page 30, for $-40°$, read $-37°.9$.

METEOROLOGY.

CHAPTER I.

HISTORY AND SCOPE OF METEOROLOGY.

1. METEOROLOGY was originally applied to the consideration of all appearances in the sky, astronomical as well as atmospherical; but the term is now restricted to that department of natural philosophy which treats of the multifarious phenomena of the atmosphere that relate to weather and climate, their relations to each other, and the laws to which they are subservient.

2. The objects which astronomy takes cognisance of being few in number, and the laws by which their motions are regulated being also few, it is comparatively easy to account for the phenomena, and, from a few data, to assign to the heavenly bodies their past, present, and future positions. But it is quite different with meteorology. Owing to the complexity and intricacy of the phenomena, and the manifold influences by which they are modified and determined, it would be a task, even supposing the data before us, beyond the compass of the human intellect to give a rational and perfectly satisfactory explanation of them. Viewed in this light, meteorology is the most difficult and involved of the sciences; hence the only procedure admissible in the first place is long and patient observation, and a faithful recording of the facts observed.

3. From the nature of the subjects which make up the science of meteorology, we may infer that they occupied men's minds from a remote antiquity. The splendid and ever-varying pano-

rama of the sky, and the variations of temperature through the days and the seasons, together with the other atmospheric changes constituting the weather which affect in so powerful a manner the necessities and comfort of man, are of a nature well fitted to arrest his attention. From the time spent in the open air during the early ages, and from the imperfect protection then enjoyed against the inclemency of the seasons, the appearances which were found by experience to precede changes of weather were eagerly recorded and handed down in the sententious form of weather proverbs. In this way many valuable facts were ascertained and passed current from hand to hand, so that there is perhaps no science of which more of the leading facts and inferences have been so long incorporated into popular language.

4. Aristotle was the first who collected, in his work 'On Meteors,' the popular prognostics of the weather. A number of these were derived from the Egyptians, who had long studied the science as a branch of astronomy, while a large number were the fruit of his own observation, and bear the mark of his singularly acute and reflective mind. Theophrastus, one of Aristotle's pupils, next took up the subject, classifying the commonly received opinions of the weather under four heads—viz., the prognostics of rain, wind, storms, and fine weather. He contented himself with discussing the subject purely in its popular and practical bearings, making no attempt to explain phenomena whose occurrence appeared so irregular and capricious. Cicero, Virgil, and a few other writers, also wrote on the weather, but made no substantial additions to our knowledge; indeed, the treatise of Theophrastus contains nearly all that was known down to comparatively recent times. Partial explanations were attempted by Aristotle and Lucretius, but as they had not the elements necessary for such an inquiry, owing to the general ignorance which prevailed on matters of physical research, their explanations were necessarily vague, and abounded with reference to superstitious beliefs, often ridiculous and absurd.

5. Meteorology remained in this dormant condition for ages, and no progress was made till proper instruments were invented for making real observations with regard to the pressure, the temperature, the humidity, and the electricity of the atmosphere.

Invention of Meteorological Instruments.

6. *The Barometer.*—The discovery of the weight of the atmosphere by Torricelli in 1643, was undoubtedly the first step in the

progress of meteorology to the rank of a science. This memorable discovery, in disclosing by the elevations and depressions of the barometric column what was passing in the more elevated regions of the atmosphere, largely extended our knowledge of this element. It should be further remarked that the value of the barometer as an indicator of the weather gave an additional impetus to the study of the science.

7. *The Thermometer.*—The invention of the *air-thermometer* by Sanctorio of Padua in 1590, laid the foundation of a salutary revolution in the science, since it pointed to an exact determination of the temperature of the air, which is by far the most important element of the weather in its relation to our welfare and interests. Improvements were made on the instrument by an Italian artist about 1655, who used wider tubes, terminating in bulbs, and filled with alcohol; and by Römer, who used mercury, and, starting from the melting-point of ice, divided the tube into degrees, each equal to 100,000th part of the bulb.

8. But the great improver of the thermometer was FAHRENHEIT. He made use of two fixed points in graduating the instrument—one indicated by the melting-point of ice, and the other by the boiling-point of water at the mean pressure of the atmosphere. The former point he called 32°, the latter 212°. Any improvements that have since been made in constructing thermometers, such as self-registration, are merely matters of convenience or detail. In so far as concerns the principle, the thermometer may be regarded as having come perfect from the hands of Fahrenheit, for the instrument he invented could be reproduced by any one at pleasure, the indications being in all cases absolutely the same. This great invention soon bore excellent fruit. Small portable thermometers were constructed by Fahrenheit, which, being carried by medical men and travellers over every part of the world, furnished observations of the most valuable description. The comparative temperature of different countries became known, and the exaggerated accounts of travellers with regard to excessive heat and cold prevailing in foreign countries, were reduced to their proper meaning. Thermometers were further turned to excellent account in the arts of brewing and horticulture, and to subjects affecting public health, and thus substantial additions were made to our comforts and luxuries.

9. *The Hygrometer.*—The expansion and contraction of vegetable and animal substances, according as the moisture of the atmosphere is increased or diminished, would appear to have suggested the idea of the hygrometer, an instrument of great value in meteorology, as indicating the quantity of vapour in the air,

and inferentially the changes of weather depending thereon. These substances were used as hygrometers by the earlier meteorologists, especially by De Saussure, whose ingenious and extensive researches, conducted with the simple hair hygrometer, entitle him to be considered the founder of this department of meteorology.

10. From the period of the invention of these instruments, the number of meteorological observers was greatly increased, and a large body of well-authenticated facts of the utmost value began to be collected. The climates of particular parts of the earth were inquired into and compared together; and the science made great and rapid advances by the investigations undertaken by distinguished philosophers into the laws which regulate atmospheric phenomena.

Important Discoveries and Discussions.

11. The theory of the *Trade-Winds* was first propounded by John Hadley in the 'Philosophical Transactions' for 1735; and it may be mentioned as a curious fact that it remained altogether unnoticed for half a century, when it was independently arrived at by Dalton, and published in his essays.

12. The publication of Dalton's 'Meteorological Essays' in 1793 marks an epoch in meteorology. It was the first instance of the principles of philosophy being brought to bear on the explanation of the complex and varied phenomena of the atmosphere. The idea that vapour is an independent elastic fluid, and that all elastic fluids, whether alone or mixed, exist independently; the great motive forces of the atmosphere; the theory of winds, with their effect on the barometer, and their relations to temperature and rain; observations on the height of clouds, on thunder, and on meteors; and the relations of magnetism and the aurora borealis,—are some of the important questions discussed in these remarkable essays, with an acuteness, a fulness, and a breadth of view which leave nothing to be desired.

13. One of the most interesting and fruitful subjects of inquiry that long engaged the attention of meteorologists was *Dew*. Pictet of Geneva, Le Roy of Montpellier, Six of Canterbury, and Patrick Wilson of Glasgow, contributed valuable observations and experiments which tended to elucidate the subject. Of these, the first place is unquestionably due to Patrick Wilson, whose 'Memoirs of Certain Great Frosts at Glasgow,' about 1780, show a fidelity of observation, and a skill of interrogating nature, which have rarely been surpassed. When it is considered that he missed the point of

the argument in continuing to entertain the notion that the cold accompanying dew comes *after* instead of *before* its deposition, the genius he manifested in his experiments will appear all the more wonderful. It was reserved for Dr Wells to collect the different observations into a coherent whole, and account for all of them by the theory of dew he propounded—a theory so just and so complete that all succeeding observation and inquiry have only confirmed it. 'The Theory of Dew' was published in 1814, and must always be regarded as one of the greatest contributions made to meteorology. The subject of radiation had been discussed by Halley, but his inquiries had reference only to solar radiation, or radiation from the sun to the earth. Radiation outwards from the earth towards space, or terrestrial radiation, was first taken account of by Lambert in his 'Pyrometrie,' published in 1779. Prevost of Geneva had also published his 'Essay on Radiant Heat' in 1809, or five years before the appearance of Dr Wells's treatise. But as Dr Wells had not seen these tracts, his discoveries regarding radiation were original and independent. Besides, he made this all-important observation or discovery, which neither Wilson nor Prevost had suspected—viz., that during those nights when dew is deposited, the temperature of bodies on the earth's surface is colder than that of the surrounding air. He also ably applied the principles laid down in the essay to explain the production of ice during night at Benares in India.

14. In 1823 Daniell published his 'Meteorological Essays and Observations,' in which he discussed in a masterly manner the hygrometry of the atmosphere, solar and terrestrial radiation, the barometric measurement of heights, the trade-winds, evaporation, and natural and artificial climates. While in all these departments he contributed largely to our knowledge, his attention was most successfully turned to the investigation of the hygrometry of the atmosphere. Though the practical advantages he anticipated as likely to flow from it have not been realised, yet this difficult, and, in some points, still obscure department of meteorology, is indebted to him more than to any other philosopher. The law of the diffusion of vapour through the air, its influence on the barometric pressure, and its relations to the other constituents of the atmosphere, are among the least satisfactorily determined questions in meteorology. Since this element is so important as an indicator of storms and other changes of the weather, it is to be hoped that it will soon be more thoroughly investigated.

15. A most important addition to our knowledge of the vapour of the atmosphere was made in 1862 by Professor Tyndall of London in his experiments on radiant heat, especially as regards

the gases, by which it is shown that the vapour of water exerts extraordinary energy as a radiant and an absorbent of heat. As a consequence, the vapour dissolved in the air serves as a covering or protection to the earth, shielding it from the sun's heat by day, and from the chilling effects of its own radiation during night. It is to be expected that the discovery of the relations of atmospheric vapour to heat will soon be turned to account in explaining many questions of meteorological inquiry.

16. Humboldt's treatise on 'Isothermal Lines,' published in 1817, mark an important epoch in experimental meteorology. Dovè has since continued the investigation, and in his splendid work 'On the Distribution of Heat on the Surface of the Globe,' has given charts of the world showing the mean temperature for each month and for the year, together with charts of abnormal temperature. It is scarcely possible to over-estimate the value of this work; for though to some extent the lines are hypothetical, there can be no doubt that a close approximation to the march of temperature, and its distribution over the globe through the year, has been arrived at. The idea has been carried out with greater fulness of detail by the Government of the United States of America, in the beautiful and elaborate series of charts of temperature and rainfall published in 'The Army Meteorological Register' for 1855. In these charts, the temperature and rainfall during the different seasons for every part of the United States are laid down from accurate observations. Temperature charts of the British Islands have also been published by the Scottish Meteorological Society, for the months of January, April, July, and October, these months being representative of the four seasons. It is to be hoped, considering how much yet remains to be done in this respect, that societies and governments will undertake the preparation and publication of similar charts, which are of inestimable value, not merely as indicating the climates of different countries, but also as showing how the temperature of one country may, by the intervention of the winds, be affected by the temperature of surrounding countries. The important influence which the temperature of one country, differing materially from that of a neighbouring country at a particular season, has in causing unsettled and stormy weather in both countries at that time, is too obvious to be longer dwelt upon.

17. In connection with terrestrial temperature, the laborious investigations of Dovè, Buys Ballot, Jelinek, Quetelet, Hansteen, Kupffer, Forbes, and Glaisher in calculating the mean temperature of places for periods of five or two days, or for each day of the year, deserve to be specially noticed. An examination of

these mean daily temperatures brings out the interesting fact that over extensive parts of the earth's surface interruptions occur, at stated times in the year, to the regular rise and fall of temperature, thus pointing to widespread disturbing causes.

18. On the 15th of June 1752, Benjamin Franklin, by the happily-conceived experiment of flying a kite, identified lightning and electricity, thus giving an interest and an impetus to electrical observations. The brilliant discoveries which have recently been made on the mutual relations of electricity, magnetism, heat, motion, and the other forces of matter, lead us to indulge the hope that the application of these results to meteorology will be attended with discoveries equally brilliant and important.

Meteorological Societies and Storm-Warnings.

19. The establishment of Meteorological Societies during the last twenty years must also be commemorated as contributing in a high degree to the solid advancement of the science, which, more than any other, depends on extensive and carefully-conducted observations. In this respect the United States stand pre-eminent, the observers there numbering about 800. Great Britain is also well represented in the English and Scottish Societies, which together number about 150 observers. In Austria, Switzerland, France, Prussia, Italy, Russia, the Netherlands, and other European countries, meteorology is being widely cultivated. In Austria alone the number of stations is 108, and in Switzerland 83. Considerable attention has also been given to the rainfall in Great Britain and Ireland; and chiefly through the self-denying exertions of G. J. Symons, London, upwards of 1300 rain-gauges are now registering the rainfall of the British Islands. An inquiry has been carried on during the last six years having for its object the determination of the causes which affect the rainfall in the basins of the Rhône and Saône. Observers in Germany and Great Britain have been secured to co-operate with the French observers, and under the able management of M. Fournet, important results respecting the rainfall and the progress of storms will be obtained, so that measures may be taken to avert the calamity occasioned by those great floods which periodically carry devastation and ruin over that part of France.

20. A special object of meteorological inquiry is to ascertain the degrees of heat, cold, and moisture peculiar to different localities, and the usual periods of their occurrence, with a view to discover their effects on the health of the people, and on different

agricultural products. With regard to questions of such general interest affecting the health and food of the people, these societies have already collected much valuable information, which but for their aid could not have been obtained.

21. But perhaps none of the arts have benefited to so large an extent by the labours of meteorologists as navigation. The knowledge thereby acquired of the prevailing winds in different parts of the earth during the different seasons of the year, the region of calms, the parts of the oceans swept by devastating storms at particular seasons, and the laws of storms, has saved innumerable lives; and by pointing out the quickest routes to be followed, has shortened voyages. In connection with this department of the science, the name of Captain Maury will always be remembered with gratitude for the signal service he has rendered to navigation. The good work thus begun by him has rendered intercourse among nations safer and more expeditious; and when future observation has supplied the materials requisite to enable us to correct the mistakes and fill up the blanks of his ocean charts, the benefits this celebrated meteorologist has conferred on the human race will more conspicuously appear.

22. *Prediction of Storms.*—Another fruit of the multiplication of meteorological stations is the prediction of storms and the foretelling of the weather. It is impossible to over-estimate the value of storm-warnings to the shipping interest. In the north temperate zone, observation shows that storms almost invariably come from some westerly point, and thence follow an easterly course. Hence in the United States of America it is easy to warn seaports of the approach of storms; for as soon as a storm appears on the eastern slope of the Rocky Mountains it is signalled to the central office in Washington, followed in its march by the telegraph, and timely warning of its approach sent to the coasts which it will visit. America is thus favourably circumstanced for carrying out effectually the system of storm-warnings. On the contrary, Great Britain, France, and the rest of Western Europe are unfavourably situated to allow of timely warning being given of coming storms; because if no warning be sent till the storm has made its appearance, it is too late for the western seaports.

23. But in Europe stormy weather is almost always accompanied with a diminution in the atmospheric pressure, the centre of which, after traversing more or less of the Atlantic, arrives on the coast of Europe. The existence of this depression is made known by the barometer when its maximum is still at a considerable distance out in the ocean; and collateral information pointing to an advancing storm is to be obtained from the direction of the

wind and the cirrus cloud. Here, then, we have the materials for foretelling the approach of storms on the west coast of Europe. For though we cannot arrive at the degree of certainty of the American predictions, and telegraph to the coasts that a storm is *actually seen advancing on them*, yet from the premonitions afforded by the barometer, the wind, and the cirrus cloud, we can warn them to prepare for a storm which is likely to visit them. The giving effect to this idea constitutes the splendid contribution to practical meteorology made by Admiral Fitz Roy in February 1861, by the system of storm-warnings which has since been adopted by almost every country in Europe—a service which has made his name a household word, and entitled him to be considered as a public benefactor.

24. Owing to the present state of knowledge, a degree of uncertainty is inseparable from the storm-warnings based on these premonitions, which does not attach to predictions based on storms actually observed. This arises from the circumstance that we do not certainly know the course the storm will take ; that is, we do not know if the centre of the storm which is approaching will direct its course to the coasts of France or of England, or pass to the north of the British Islands. It is this knowledge, moreover, which it is necessary to possess in order to enable us to transmit trustworthy warnings to the different coasts. Le Verrier thus states the present position of storm-warnings in Western Europe :—"The despatch of a warning, after a storm has actually appeared on some point of the coast of Europe, is too slow. On the other hand, in the system of absolute prediction founded on premonitions of a coming storm, it is premature to draw up a real trustworthy warning. Experience, therefore, leads us to adopt a system intermediate, based on the opinion formed by competent men accustomed to the work."

25. It is therefore a duty incumbent on European meteorologists, being the most important practical problem they have to solve, to examine, analyse, and carefully study in detail the storms which have traversed Europe during the last few years, when, from the growing popularity of the science, meteorological stations have largely increased, with the view of ascertaining the course storms follow and the causes by which that course is determined, so as to deduce from meteorological phenomena observed not only the certain approach of a storm, but also the particular course it will take in its passage over Europe.* In carrying out this extensive investigation, the 'Bulletin International' of Le Verrier, published daily, if supplemented with additional observations from places in the British Islands, in Northern, Eastern, and South-Eastern

Europe, will furnish the required materials. This admirable publication, which must be regarded as the latest important step taken in the progress of meteorology, shows graphically the atmospheric pressure, and the direction and force of the winds each morning over Europe, together with tables of temperature, rainfall, cloud, and sea disturbance.

26. In the schools of the United States of America, meteorological observations, and the keeping of meteorological registers, form a part of the common education of the people. Also in the higher schools of France, and some other European countries, systematic instruction is communicated on this subject. But in this country few even of the liberally educated classes are able to read from a vernier; are ignorant of the use of the movable cistern of a barometer; have not the elementary knowledge to give an intelligible interpretation to the fluctuations of the barometer as indicative of coming changes of the weather; and when required to send their barometers to a distance for repair, forward them by rail as ordinary parcels, thus almost to a certainty securing their destruction. This state of things is the necessary consequence of the general neglect which meteorology receives in our educational system. There are, however, a few noteworthy exceptions. Meteorology has been taught for upwards of thirty years in the Dollar Institution, which has long been distinguished for the lead it has taken in incorporating science into its curriculum of study. This example has recently been followed by the Roman Catholic College at Stonyhurst, the Grammar School of Aberdeen, the High School of Inverness, Elgin Institution, Larchfield Academy, and several country schools. But the objects of meteorology can never hold that place in the public mind to which they are entitled till the science become, as in America, a recognised branch of education. As contributing towards this desired result, the name of Thomas H. Core deserves special mention in having, while mathematical master in the Church of Scotland Edinburgh Normal School, systematically trained the students to regular habits of meteorological observation. When the law of storms begins to be generally understood, and, as a consequence, the value of observations of the barometer, the direction of the wind, and the appearances of the clouds, comes to be appreciated as heralding changes of the weather, we cannot doubt that this very practical age will take steps to provide for the instruction of the people in the elementary facts of meteorology, and in the use of the different meteorological instruments.

CHAPTER II.

THE WEIGHT OR PRESSURE OF THE ATMOSPHERE.

27. A *Barometer* is the instrument employed to measure the height of a column of mercury supported by the pressure of the atmosphere. From this the weight of the atmosphere is ascertained. The fundamental principle of the barometer cannot be better illustrated than by the experiment which led Torricelli to discover the weight of the atmosphere. Take a glass tube (fig. 1), 33 inches in length, open at one end; fill it with mercury, and, closing the open end with the finger, invert it, and plunge the open end into a bowl also containing mercury. The column will fall in the tube to about 30 inches above the surface of the mercury in the bowl, if the experiment be made near the level of the sea. The fluid is upheld in the tube by the air outside of it pressing on the mercury in the bowl; and since the one thus balances the other, it is evident that the mercurial column will serve as an accurate indicator of the varying pressure of the air. The space *a b* in the tube above the mercury is the nearest approach to a vacuum that can be made, and is called the *Torricellian vacuum.*

Fig. 1.

28. The heights of the columns of two fluids in equilibrium are inversely as their specific gravities; and as air is 10,784 times lighter than mercury, the height of the atmosphere would be 10,784 times 30 inches, or nearly five miles, if it was composed of layers equally dense throughout. But since, from the diminished pressure and its great elasticity, air becomes less dense as we ascend, the real height is very much greater, being probably about eighty miles.

29. Other fluids may be used in the construction of barometers,

which, being lighter than mercury, have columns proportionally longer. Thus, if water, which is nearly 14 times lighter than mercury, be used, the barometric column is about 35 feet long. The advantage *Water Barometers* might be suppossed to possess in showing changes of atmospheric pressure on a large scale, is more than counterbalanced by a serious objection. The space in the tube above the water is not a true vacuum, but is filled with aqueous vapour, which presses on the water with a force varying with the temperature. If the temperature is 32° the column is depressed half an inch, and if it is raised to 75° it is depressed a foot. In mercurial barometers the space in the top of the tube is no doubt filled with the vapour of mercury, but it exerts so slight a pressure that the amount of the depression, even at the ordinary temperature of a sitting-room, could not be measured by the finest graduated vernier. Since no fluid approaches mercury in this respect, it is universally used in constructing the best barometers.

30. The tubes of barometers must be filled with pure mercury. If the mercury is not pure the density will be different, and consequently the length of the column will not be the same as that of a barometer in which pure mercury has been used; and, moreover, the impurities will soon appear in the mercury, causing it to adhere to the tube, and thus impeding its action as it rises and falls, and rendering the instrument useless for accurate observation.

31. In filling tubes, air and moisture get mixed up with the mercury, and if not expelled will soon ascend to the top of the tube, and, forming an atmosphere there, depress the column. The air and moisture is expelled by boiling the mercury in the tube, always a difficult operation, requiring the utmost precaution and care, so as to expel the air wholly without breaking the tube. As it is absolutely essential that a barometer be quite free from air and vapour, it should be tested some time after it has been boiled, and before it is used. This is done by gently inclining it, so that the mercury may strike against the top of the glass tube. If there be no air within, a sharp metallic click will be heard; but if the sound is dull, the air has not been completely expelled.

32. Barometers are commonly divided into two classes—*cistern barometers* and *siphon barometers*, the most important of these being the cistern barometer. Fig. 1 shows the *Cistern Barometer* in its essential and simplest form, and it only requires a scale, extending from the surface of the mercury in the cistern to the top of the tube, to make it complete. Cistern barometers are subject to two sorts of error, arising from capillarity, and from changes of level in the cistern as the mercury rises and falls in the tube.

33. The effect of *capillarity* is to depress the column, the amount of the depression depending on the internal diameter of the glass tube. Thus, if the diameter of the tube be half an inch, the error arising from capillarity is only .003 inch; if the diameter is $\frac{1}{3}$ inch, the error is .012 inch; if the diameter is $\frac{1}{4}$ inch, the error is .020 inch; and if the diameter is $\frac{1}{8}$ inch, the narrowest tube that should ever be used, the error is .070 inch. Hence cistern barometers require an addition to be made to the observed height to give the true height.

34. The other error is technically called the *error of capacity*, and arises in this way: The height of the barometer is the distance between the surface of the mercury in the cistern and the upper surface of the column. Now suppose the barometer falls from 30 inches to 29 inches, an inch of mercury must *flow out of the tube, and pass into the cistern*, thus raising the level of the cistern; if, on the other hand, it rises from 29 inches to 30 inches, mercury must flow back from the cistern into the tube, thus lowering the level of the cistern. Hence, then, owing to the incessant changes in the level of the cistern, the readings on the *fixed scale* are sometimes too high and sometimes too low. The simplest and rudest way for compensating for this error is to ascertain (1) the *neutral point* of the instrument—that is, the height at which it stands when the zero of the scale is on a level with the surface of the mercury in the cistern, or when it agrees with a standard barometer; and (2) the rate of the error as the column rises or falls above this point, and apply a correction proportioned to this rate. This is not only a clumsy method, but, as it involves some computation, it would give rise to frequent mistakes. The error is the less the more the surface of the cistern exceeds that of the column in the tube, because the fall or rise in the tube is spread over a larger surface. Hence it is desirable that the cisterns of barometers be made as large as possible.

35. The barometer in which the error of level is entirely got rid of is one invented by FORTIN; and since it is the best cistern barometer, we here describe it, or rather that modification of it in most general use in this country, figs. 2 and 5. In fig. 2,

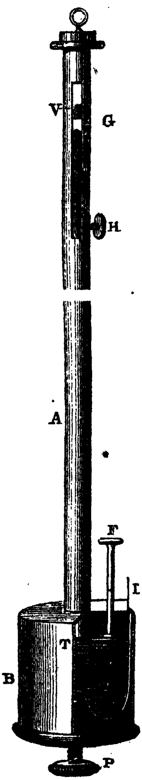


Fig. 2.

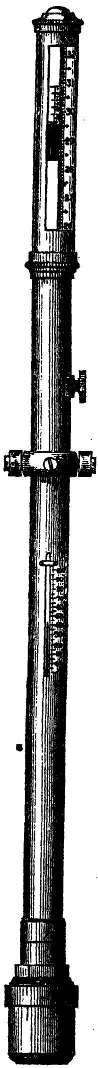


Fig. 3.

B is a brass box containing the cistern, C, the walls of which are of boxwood, but the bottom of flexible leather. This cistern contains the mercury into which the glass tube is plunged. P is a screw, which works through the bottom of the brass box, B, against the flexible bottom of the cistern, by which the level of the mercury is raised or depressed at will. F is a small ivory piston or float resting on the surface of the cistern, and moving freely between the two ivory supports, I. There will also be observed horizontal lines on the ivory float and supports, *which are drawn so as to lie in the same straight line only when the surface in the cistern is at the neutral point* from which the scale, G, of the instrument has been graduated. Hence, then, with every observation, the screw, P, must be turned either way till these lines lie in the same straight line. The glass tube, the lower part of which is seen plunged into the mercury in the cistern at T, is enclosed in a brass tube, which extends continuously from the brass box, B, to the top of the instrument. This brass tube is made with two opposite slits for the purpose of showing the height of the column. In these slits is placed a vernier, V, which slides up and down by turning the screw, H. When the height of the barometer is required to be taken, the screw H is turned till the horizontal edge of the vernier forms a tangent to the convex curve of the mercury, as at fig. 4. Care must be taken to avoid a mistake not unfrequently made in shutting off the whole light; that is, instead of making the vernier a tangent to the mercurial curve, as it should be, it is made the arc of that curve.

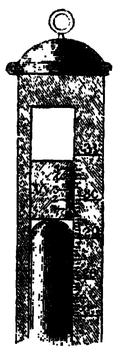


Fig. 4.

36. A *Travelling Barometer*, fig. 3, has been constructed by Adie of London, which, since it possesses several advantages as a practical instrument, deserves to be noticed. The error of capillarity is allowed for in fixing the zero point of the scale. The error of capacity is obviated by making the

inches of the scale not true inches, but just so much less as exactly counterbalances the error of capacity. The diameter of the glass tube is generally contracted in its middle part, by which risk of breakage from pumping as it is conveyed from place to place is so much lessened that it may be sent as a parcel by rail, if only the most ordinary care be taken in removing it in and out of the carriages. When the tube is very much narrowed the greater part of its length, it forms the ordinary *Marine Barometer*. It is also frequently made with a Lussac chamber, by which any air that may happen to find its way into the tube by the cistern is arrested in its ascent towards the top, and the instrument sustains no damage from the accident. Since this barometer may be conveyed from place to place with comparative safety, is not liable to injury from the introduction of air into the Torricellian vacuum, and requires no preliminary adjustment of the cistern before making an observation, it is rapidly gaining favour with the public.

37. As the common cistern barometers are liable to be deranged by the introduction of air into their tubes on removal from place to place, or in being roughly handled, it is useful to know how the air may be expelled. First, close up the cistern, fig. 2, so as to prevent the escape of mercury by fixing the ivory piston, F, which acts as a stopper to the cistern on being screwed up tight; then by the screw, P, raise the mercurial column to about half an inch from the top of the tube; and having slowly inverted the instrument, place the top of it against a yielding substance, such as the boot, and tap gently on the cistern with the palm of the hand, so as to induce the air to ascend to the cistern, whence it may escape. Since there is the weight of two atmospheres—the mercury in the barometer and the air outside—pressing on any air that may be inside the tube, it is usually a tedious operation to get it wholly expelled. After repeated trials, however, it is generally accomplished; and the clear metallic click of the mercury, when struck against the top of the tube, by gently inclining the barometer, will show when the whole of the air has been got quit of. On hanging up the barometer, care must be taken to lower the mercury in the tube by turning the screw, P, before unfastening the float, F; for if this be not attended to, the pressure applied by the screw, P, will cause the mercury to

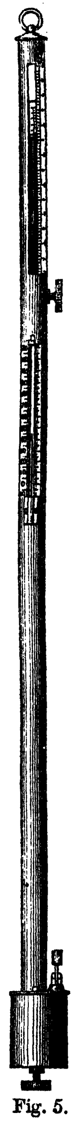


Fig. 5.

flow out at the aperture of the float, causing serious damage to the instrument.

38. In hanging or fixing the barometer, a perfectly perpendicular position must be secured; for if this be not attended to, the readings will be higher in proportion to the amount of the deviation from the perpendicular. Thus if, instead of hanging in a perpendicular line, it slant a little, it may read a tenth or more above what it ought to read. Hence, to obviate this risk of error, it is always preferable that barometers swing in position.

39. The *Siphon Barometer*, fig. 6, is made of a tube bent in the form of a siphon, and of the same diameter throughout. A graduated scale passes along the whole length of the tube, and when an observation is made, the readings at the lower and upper limbs are taken, and the difference between them is the height. There is another form of this instrument, in which, by means of a screw acting from below, the tube is made to slide along the scale, and hence in observing it is only necessary to set the surface of the mercury in the lower limb to the neutral point of the scale, and the pressure is seen at once from the upper limb. Since in siphon barometers the capillary attraction at both surfaces is the same, no error arises from this cause; and still further there is no error of capacity from difference of level as in cistern barometers. But these advantages are counterbalanced by two disadvantages: 1, the trouble of taking two observations, and the chance of mistake which would frequently arise in taking the difference of the two; and, 2, the free contact of the open lower limb with the air, by which the mercury gets foul, and, adhering to the tube, impedes the smooth working of the instrument. In narrow tubes this becomes a very serious objection.

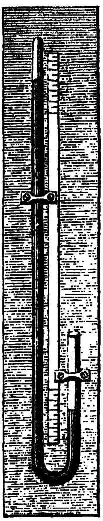


Fig. 6.

40. The common *Wheel Barometer*, the popular form of the *weather-glass*, is a modification of the siphon barometer. A small weight, glass or iron, floats on the mercury in the lower limb of the siphon: to this weight a thread is attached, which is led round a horizontal axis, a small weight being suspended at its free extremity to keep it tight. The glass float rises and falls with the fluctuations of the barometer, and a pointer fixed to the horizontal axis being turned by this means indicates the pressure on a dial. Since the mercury only rises or falls in the open end of the siphon to the extent of half the oscillation, a cistern is added to the top to increase the amount of the variation

in the lower limb. The lengthening and shortening of the thread with the dampness or dryness of the air, and the friction of the different parts, are causes of large and uncertain errors in this form of the barometer, and hence it cannot be used where accuracy is required. It is, however, useful in indicating roughly the more marked atmospheric fluctuations which are generally accompanied by changes of the weather.

41. *Howson's Barometer* deserves to be noticed, not only for the great ability and ingenuity displayed in its invention, but because it may be justly considered as the best adapted for scientific purposes of that class of barometers which aim at great sensitiveness by increased range being given to their fluctuations. Fig. 7 shows the essential and peculiar parts of the instrument. A is the barometer tube, which is of large diameter, and longer than the ordinary sort, so as to admit of a greater length of range. B is a cylindrical cistern, having attached to the bottom of it a long hollow tube or stalk, C, hermetically sealed, springing to a height of about 28 inches above the fixed level of the mercury in the cistern. The stalk, *c*, terminates a little below the upper level of the mercury, *a*, and its upper end is therefore exposed to no more downward pressure than that of the mercury above it; consequently there is an excess of upward pressure from the atmosphere which tends to raise the cistern. When the excess of upward pressure is exactly balanced by the weight of the cistern with its stalk and contained mercury up to *b*, an equilibrium will be established which will keep the cistern stationary or hanging in suspension. Suppose now that the atmospheric pressure acting on the cistern is increased, and that the thickness of the glass tube, A, immersed in the cistern, is nothing, the cistern will continue to ascend to an indefinite extent, there being nothing to stop it. The glass is, however, a substance of some thickness, displacing mercury as it is plunged into the cistern; and as it thus presents a resistance to the ascent of the cistern, the latter will come to rest when the quantity of mercury displaced is equivalent to the increase of pressure. The extent of range which this instrument possesses above the ordinary barometer is determined by the ratio of the internal area of the tube, A, to the annulus of glass which bounds it. If those two are equal the range is doubled, and if the internal area is greatly in excess the range is proportionately increased.

Fig. 7.

42. The principle on which the *Aneroid Barometer* depends is the varying pressure of the atmosphere upon an elastic metallic chamber partially exhausted of its air, and so constructed that by a system of levers a motion is given to an index-hand which moves upon a dial. As it is very portable, and is not liable to be broken in carriage like mercurial barometers, it is peculiarly suited for nautical purposes, and for taking the heights of mountains. It requires, however, to be occasionally compared with a standard mercurial barometer, being liable to variation from the elasticity of the brass of the chamber changing, or from changes in the system of levers which work the index-hand. Though aneroids may be constructed showing great accuracy in their indications, yet none can lay claim to the exactness of mercurial barometers.

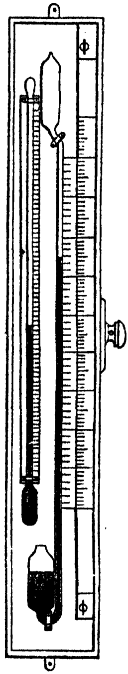


Fig. 8.

43. The *Sympiesometer*, fig. 8, was invented by Adie. It consists of a glass tube, 18 inches in length and $\frac{3}{4}$ inch in diameter, with a small chamber at the top, and an open cistern below. The upper part of the tube is filled with hydrogen gas, and the lower part and cistern with oil of almonds coloured red. Hence when the pressure of the atmosphere is increased, the hydrogen is compressed, and the coloured fluid rises; but when it is diminished, the hydrogen expands and the fluid falls. To obviate error from the increased pressure of the gas when its temperature is raised, a thermometer and sliding scale are added to the instrument, so that it may be adjusted to the temperature with each observation. It is a very sensitive instrument, and well adapted for being used at sea and by travellers; but it is not suited for exact observation, being liable to change from the oil absorbing the hydrogen gas.

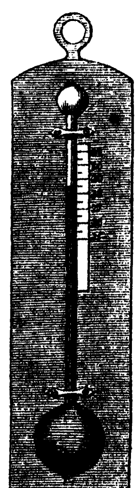


Fig. 9.

44. The *Hermetic Barometer*, or *poor man's weather-glass*, fig. 9, consists of a glass tube with a large, *nearly flat* bulb of thin glass at the base, filled as in the sympiesometer, and then hermetically closed. The thin glass of the bulb being elastic, is subject to

compression and dilation as the atmospheric pressure is increased or diminished; and as a small quantity of gas is left in the top of the tube, the column of coloured oil rises or falls with the pressure of the air. To insure uniformity in its working, it requires to be kept as near as possible at the same temperature. It is of no use as a scientific instrument; but it may be referred to as the cheapest instrument by which variations in the atmospheric pressure may be roughly indicated.

45. *Reduction of Barometric Readings to* 32°.—Mercury expands $\frac{1}{9990}$ of its bulk for every degree of Fahrenheit's thermometer; if, then, a barometer stands at a height of 30 inches when the temperature of its mercury is 32°, it will stand at $30\frac{1}{10}$ inches if the temperature be raised to 69°. This increase of the length of the column by the tenth of an inch, is not due to any increased pressure, but solely to the expansion of the mercury under a higher temperature. In order, therefore, to compare barometric observations together with exactness, it is necessary to reduce them to the heights at which they would stand at some uniform temperature. The temperature to which they are generally reduced is 32°. The correction for this reduction is found by dividing by 9990 the difference between the observed temperature and 32°, and subtracting or adding the result to the observed height, according as the temperature is above or below 32°.

46. Table I. gives the temperature corrections, adopted by the Royal Society of London, in decimals of an inch for every degree from 29° to 87°, and for every half-inch from 27.5 to 30.5 inches. The scale is supposed to be brass, extending from the cistern to the top of the column, the difference between the expansion of brass and mercury being allowed for in the table. Since the standard temperature of the yard is 62°, and not 32°, the difference of expansion of the scale and the mercurial column carries the point of no correction down to 28°.5.

47. The column of mercury in the tube is supported above the level of the mercury in the cistern by the pressure of a column of the atmosphere having the same base as itself. Hence the weight of this atmospheric column is the same as that of the column of mercury. Now, if we suppose the mercurial column to be 30 inches, which is nearly the average height at the level of the sea, and its base a square inch, it will contain 30 cubic inches of mercury; and since one cubic inch of mercury contains $3426\frac{3}{4}$ grains, the weight of 30 will be nearly 14.7 lb. avoirdupois. Thus the pressure of the atmosphere on every square inch of the earth's surface is 14.7 lb.

48. *Mode of estimating Atmospheric Pressure.*—The pressure

of the atmosphere is not measured by the weight of the mercury sustained in the tube by that pressure, but by the perpendicular height of the column. Thus when the height of the column is 30 inches, we do not say that the atmospheric pressure is 14.7 lb. on the square inch, but that it is 30 inches, meaning that the pressure will sustain a column of mercury at that height.

49. In England and America the height of the barometer is expressed in English inches, and in Russia by *half-lines.* As a half-line equals half an English decimal line, the Russian barometric observations are at once reduced to the scale of English inches by dividing by 20. In France and most countries of Europe the height is expressed in millimetres—a millimetre being the thousandth part of the French metre, which equals 39.37079 English inches. Table II. will be found useful in comparing these two scales. The old French scale, in which the unit is the French or Paris line (0.088814 inch), is still in use in a few countries on the Continent. The English measure of length being a standard at 62° Fahr., the old French measure at 61.2°, and the modern French at 32°, it is necessary, before comparing observations taken with the three barometers, to reduce them to the same temperature, so as to neutralise the inequalities arising from the expansion of the scales by heat.

50. *Correction for Height.*—In comparing barometric observations at different places, we must take account of their respective heights above the sea; for as we rise above the level of the sea, a portion of the atmosphere is left behind, and the pressure being thereby diminished, the height of the column is less. Hence an addition requires to be made proportional to the height of each station above mean sea-level. This addition is technically called "*correction for height.*" The amount of this correction is determined by the height of the place above the sea, the atmospheric pressure and temperature at the time, and the distance from the centre of gravity of the earth, which is known from the latitude and height above the sea.

51. The correction for *Decrease of Gravitation* at the high situation, as compared with the force of gravity at sea-level, is small, amounting only to 0.001 inch for about 400 feet. Owing to the form of the earth, places at the equator are further removed from the centre of gravity than at the poles, and hence air, in common with other terrestrial bodies, weighs less at the equator than at the poles. It follows, therefore, in reducing observations made in different latitudes, that an addition requires to be made to observations at the equator, which, as we proceed toward the poles, becomes less and less, till it falls to zero at latitude 45°.

For higher latitudes a subtraction will require to be made, which will constantly increase to the maximum at the poles. This *correction for the difference of gravity in various latitudes* is also small, being less than 0.001 inch for 1000 feet in Great Britain, and less than 0.003 inch near the equator and the poles. We may, therefore, in an elementary work of this description, neglect these two corrections.

52. Since air is denser when the pressure is 30.5 inches than when it is 28.5 inches, the correction for height will be considerably greater in the one case than in the other. And again, since the same volume of air is lighter, *cæteris paribus*, at a temperature of 60° than at 32°, a smaller correction for height will be required at 60° than at 32°. At a temperature of 32° and a pressure of 30 inches, 868½ feet of air balances one inch of mercury. The coefficient expressing the expansion of air by heat, as determined by Guy-Lussac, is 0.0021 of its bulk for one degree Fahrenheit. Hence, when the temperature rises to 33°, the column of air necessary to balance 1 inch of mercury will be 870.4 feet—that is, the raising of the temperature one degree has pushed the air up about 2 feet over places 868 feet above the sea; and the atmospheric pressure being thus increased, the correction for height becomes less. Let H be the height in feet of a column of air at the given temperature required to balance 1 inch of mercury; f the height of the place above sea-level; h the reading of the barometer reduced to 32°, and 30 the mean barometric height, then—

$$\text{The correction for height} = \frac{f \times h}{H \times 30}.$$

53. Table III. gives the corrections for heights thus worked out, which it is hoped will be found sufficient for most practical purposes. The intermediate numbers may be interpolated with little trouble.

54. *Example showing the Reduction of the Barometer to* 32° *and Sea-level.*—At Edinburgh, during February 1866, the mean daily height of the barometer was 29.357 inches, the attached thermometer 50°, and the mean temperature of the air 38°, the height of barometer above mean sea-level being 270 feet.

Observed mean height, ...	29.357 inches.
Correction required at 50° (Table I.), .	—.057
Reduced to 32°, ...	29.300
Correction for height, 270 feet, air being 38°,	+.286
Reduced to 32° and sea-level, ...	29.586

Hence if the Edinburgh observations during February 1866 had been made at mean sea-level, and the temperature remained at

32°, the mean barometric height for the month would have been 29.586 instead of 29.357.

55. The above formula and table give only the approximate correction for height,—an approximation, however, so close that it may be regarded as practically correct for at least all places that do not exceed 4000 feet in height.

56. *Mode of taking Averages or Means.*—It may be here observed that the *mean* for any month is found by adding together the whole of the observations taken during the month and dividing the sum by the number of them.

57. *Barometric Measurement of Heights.*—It would be out of place here to give the more exact formula for determining heights by means of barometric observations, since to be of any value it would require to be accompanied by a series of tables quite beyond the scope of an elementary treatise. Table III. may be used for the determination of heights with sufficient accuracy for general purposes, and it may be easily enlarged so as to include all places and heights in Great Britain. A double set of observations made simultaneously is necessary—one at the place whose height it is required to determine, and the other at the level of the sea or at a place whose height is known and as near the former as possible. At each place the height of the barometer, the attached thermometer, and the temperature of the air *in shade* require to be observed. Thus, to take a simple case:—Suppose the barometer at the lower station, or at the sea-level when reduced to 32°, to be 30 inches, and temperature of the air 54°; and the barometer at the higher station 28 inches, and temperature of the air 46°. The mean of the two temperatures being 50° and the difference of the barometers 2 inches, we shall find if we cast our eye down the column of 30 inches in Table III. and temperature of 50° (52°), that 2 inches stands opposite 1800 feet. The higher station is therefore about 1800 feet above the sea. In cases where simultaneous observations cannot be had at the sea-level, the height may be determined from observations made at some known height above the sea with which, being reduced to sea-level, the observations at the higher place may be compared.

58. *Variations of the Barometer.*—The variations observed in the pressure of the air may be divided into two classes—viz., periodical and irregular; the periodical variations recurring at regular intervals, whilst the irregular variations observe no stated times. The most marked of the periodical variations is the *daily variation,* the regularity of which in the tropics is so great that, according to Humboldt, the hour may be ascertained from the height of the barometer without an

error of more than 15 or 17 minutes on the average. This horary oscillation of the barometer is masked in Great Britain by the frequent fluctuations to which the atmosphere is subjected in these regions. It is, however, detected by taking the mean of a series of hourly observations conducted for some time. The results show two maxima occurring from 9 to 11 A.M. and from 9 to 11 P.M., and two minima occurring from 3 to 5 A.M. and from 3 to 5 P.M.

TABLE SHOWING THE DAILY VARIATIONS AND RANGE OF THE BAROMETER IN DIFFERENT LATITUDES.

	Lat.	A.M.		P.M.		Range.
		Min.	Max.	Min.	Max.	
		Inches.	Inches.	Inches.	Inches.	Inches.
Atlantic Ocean,	0.0	—.056	+.069	—.045	+.045	.125
Pacific Ocean,	0.0	—.032	+.040	—.045	+.028	.085
Sierra Leone,	8.28 N.	—.022	+ 032	—.038	+.031	.070
Lima,	12.3 S.	—.071	+.065	—.067	+.050	.136
Calcutta,	22.36 N.	—.017	+.052	—.038	+.018	.090
Rio Janeiro,	22.57 S.	—.036	+.040	—.040	+.030	.080
Pekin,	39.53 N.	—.038	+.047	—.052	+.014	.099
Padua,	45.24 N.	—.004	+.012	—.014	+.007	.026
Great St Bernard,	45.51 N.	—.010	+.005	—.003	+.012	.022
Plymouth,	50.21 N.	—.007	+.006	—.010	+.010	.020
Barnaul,	53.14 N.	—.008	+.016	—.007	+.005	.024
St Petersburg,	59.58 N.	—.003	+.008	—.004	+.002	.012
Bossekop,	66.58 N.	—.007	+.006	—.002	+.003	.013

The maxima occur when the temperature is about the mean of the day, and the minima when it is at the highest and lowest respectively.

59. This daily fluctuation of the barometer is caused by the changes which take place from hour to hour of the day in the temperature and by the varying quantity of vapour in the atmosphere.

60. The surface of the globe is always divided into a day and night hemisphere, separated by a great circle which revolves with the sun from east to west in twenty-four hours. These two hemispheres are thus in direct contrast to each other in respect of heat and evaporation. The hemisphere exposed to the sun is warm, and that turned in the other direction is cold. Owing to the short time in which each revolution takes place, the time of greatest heat is not at noon, when the sun is in the meridian, but about two or three hours thereafter; similarly, the period of greatest cold occurs about four in the morning. As the hemisphere under the sun's rays becomes heated, the air, expanding upwards and outwards, flows over upon the other hemisphere where

the air is colder and denser. There thus revolves round the globe from day to day a wave of heat, from the crest of which air constantly tends to flow towards the meridian of greatest cold on the opposite side of the globe.

61. The barometer is influenced to a large extent by the elastic force of the vapour of water invisibly suspended in the atmosphere, in the same way as it is influenced by the dry air (oxygen and hydrogen). But the vapour of water also exerts a pressure on the barometer in another way. Vapour tends to diffuse itself equally through the air; but as the particles of air offer an obstruction to the watery particles, about 9 or 10 A.M., when evaporation is most rapid, the vapour is accumulated or pent up in the lower stratum of the atmosphere, and being impeded in its ascent its elastic force is increased by the reaction, and the barometer consequently rises. When the air falls below the temperature of the dew-point, part of its moisture is deposited in dew, and since some time must elapse before the vapour of the upper strata can diffuse itself downwards to supply the deficiency, the barometer falls—most markedly at 10 P.M., when the deposition of dew is greatest.

62. Hence, as regards temperature, the barometer is subject to a maximum and minimum pressure each day,—the maximum occurring at the period of greatest cold, and the minimum at the period of greatest heat. And as regards vapour in the atmosphere, the barometer is subject to two maxima and minima of pressure—the maxima occurring at 10 A.M., when, owing to the rapid evaporation, the accumulation of vapour near the surface is greatest, and about sunset, or just before dew begins to be deposited, when the relative amount of vapour is great; and the minima in the evening, when the deposition of dew is greatest, and before sunrise, when evaporation and the quantity of vapour in the air is least.

63. Thus the maximum in the forenoon is brought about by the rapid evaporation arising from the dryness of the air and the increasing temperature. But as the vapour becomes more equally diffused, and the air more saturated, evaporation proceeds more languidly; the air becomes also more expanded by the heat, and flows away to meet the diurnal wave of cold advancing from the eastwards. Thus the pressure falls to the afternoon minimum about 4 P.M. From this time the temperature declines, the air approaches more nearly the point of saturation, and the pressure being further increased by accessions of air from the warm wave, now considerably to the westward, the evening maximum is attained. As the deposition of dew proceeds, the air becomes drier, the elastic pressure of the vapour is greatly diminished, and the pressure falls to a second minimum about 4 A.M.

64. The amount of these daily variations diminishes from the equator towards either pole, for the obvious reason that they depend, directly or indirectly, on the heating power of the sun's rays. Thus, while at the equator the daily fluctuation is 0.125 inch, in Great Britain it is only a sixth part of that amount. It is very small in the high latitudes of St Petersburg and Bossekop; and in still higher latitudes, at that period of the year when there is no alternation of day and night, the diurnal variation probably does not occur. In the dry climate of Barnaul, in Siberia, there is no evening maximum; the lowest minimum occurs as early as midnight, and the only maximum at 9 A.M.

65. Since the whole column of the atmosphere, from the sea-level upwards, expands during the heat of the day, thus lifting a portion of it above all plaees at higher levels, it is evident that the afternoon minimum at high stations will be less than at lower stations, especially when the ascent from the one to the other is abrupt. Thus, at Padua, in Italy, the afternoon minimum is 0.014 inch, but at Great St Bernard it is only 0.003 inch.

66. *Annual Variation.*—When it is summer in the one hemisphere, it is winter in the other. In the hemisphere where summer prevails, the whole air, being warmer than in the other hemisphere, expands both vertically and laterally. As a consequence of the lateral expansion there follows a transference of part of the air from the warm to the cold hemisphere along the earth's surface; and, as a consequence of the vertical expansion, an overflow in the upper regions of the atmosphere in the same direction. Hence, in so far as the dry air of the atmosphere is concerned, the atmospheric pressure will be least in the summer and greatest in the winter of each hemisphere. But the production of aqueous vapour by evaporation being most active in summer, the pressure on the barometer will be much increased from this cause. As the aqueous vapour is transferred to the colder hemisphere it will be there condensed into rain, and being thereby withdrawn from the atmosphere, the barometer pressure will be diminished; but the dry air which the vapour brought with it from the warm hemisphere will remain, thus tending to increase the pressure.

67. In the neighbourhood of the equator there is little variation in the mean pressure from month to month. Thus, at Cayenne, the pressure in January is 29.903 inches, and in July 29.957 inches.

68. At Calcutta, 22° 36′ N. lat., the pressure is 29.408 in July, and 30.102 in January, thus showing a difference of 0.694; and at Rio de Janeiro, 22° 57′ S. lat., it is 29.744 in January (summer), and 29.978 in July (winter), the difference being 0.234. The large

annual variation at Calcutta is caused jointly by the great heat in July, and by the heavy rains which accompany the south-west monsoons at this season; while in January the barometer is high, owing to the north-east monsoons, by which the dry cold dense air of Central Asia is conveyed southward over India.

69. At places where the amount of vapour in the air varies little from month to month, but the variations of temperature are great, the difference between the summer and winter pressures are very striking. Thus, at Barnaul and Irkutsk, both in Siberia, the pressures in July are respectively 29.243 and 28.267, and in January 29.897 and 28.865, the differences being upwards of six-tenths of an inch. The great heat of Siberia during summer causes the air to expand and flow away in all directions, and the diminished pressure is not compensated for by any material accessions being made to the aqueous vapour of the atmosphere; and, on the other hand, the great cold and little rain in that region during winter causes high pressures to prevail during that season. The same peculiarity is seen, though in a modified degree, at Moscow, St Petersburg, and Vienna.

70. At Reykjavik, in Iceland, the pressure in June is 29.717, and in December 29.273; at Sandwich, Orkney, 29.775, and 29.586; and at Sitcha, in Russian America, 29.975, and 29.664. In all these places the distribution of the pressure is just the reverse of what obtains in Siberia, being least in winter and greatest in summer. The high summer pressures are due to the cool summer temperature as compared with surrounding countries, thus causing an *inflow from these regions*, and to the large amount of vapour in the atmosphere, thus still further raising the barometric column. On the other hand, the low winter pressures are due to the comparatively high winter temperatures causing an *outflow towards adjoining countries*, and the large winter rainfall, which, by setting free great quantities of latent heat, still further augments and accelerates the outflow.

71. The variations in mean pressure are very slight, and not marked by any very decided regularity in their march through the seasons, at Dublin, Glasgow, London, Paris, and Rome. As compared with Barnaul and Reykjavik their temperature is at no season very different from that of surrounding countries, and the vapour and rainfall are at no time much in excess or defect, but are more equally distributed over the different months of the year.

72. At the Great St Bernard, 8174 feet above the sea, the pressure in summer is 22.364 inches, while in winter it is only 22.044. At Padua, there is scarcely any difference in the pressure between summer and winter. The increase in the summer pressure at the

Great St Bernard is no doubt due to the same cause already referred to in art. 65—viz., the expansion of the air upward during the warm summer months, thus raising a larger portion of it above the barometer at the higher station. But at St Fe de Bogota, 8615 feet high, near the equator, and where, consequently, the difference between the temperature in July and January is very small, the difference in the pressures of the same months is also very small, being only 0.035.

73. *Distribution of Atmospheric Pressure over the globe, as determined by the Annual Means.*—Though much additional observation is required, especially in Africa, Asia, and South America, before the isobarometric lines can be laid down on a map of the world, yet many important conclusions regarding the mean barometric pressure have been arrived at from the results already obtained. We have seen that the daily and monthly variations of pressure observed at different places are modified by the variations of the temperature of the air, the amount of vapour, and the rainfall. Since these are in their turn greatly modified by the unequal distribution of land and water on the earth's surface, we should expect to find the pressure, and the variations in the pressure, most regular in the southern hemisphere. Accordingly, there is a remarkable regularity observed in the distribution of the pressure from about 40° N. lat. southwards to the Antarctic Ocean, with the exception of the region of the monsoons in Southern Asia, as may be observed from the following table of mean pressures reduced to the level of the sea :—

	Latitude North.	Mean Pressure in inches.		Latitude South.	Mean Pressure in inches.
Rome . .	41.54	30.015	Ceara . . .	3.43	29.859
Azores . .	37.35	30.121	St Helena . .	16.0	30.136
Athens . .	37.58	30.130	Bourbon . .	20.50	30.050
Algiers . .	36.43	30.236	Rio Janeiro . .	22.57	30.023
Madeira .	32.46	30.107	Cape Town . .	34.56	30.008
Nangasaki .	32.45	30.000	Melbourne . .	37.49	29.964
Macao . .	22.20	30.046	Dunedin . . .	45.53	29.880
St Thomas .	18.23	30.060	Board of Trade Registers on a mean of upwards of 100,000 observations *	45 to 50	29.740
Manila . .	14.53	29.900		50 to 55	29.460
Madras . .	13.4	29.900		55 to 60	29.240
Trivandrum	8.30	29.820		60 to 65	29.130
Christiansburg	5.36	29.850		65 to 70	29.070
Cayenne .	4.49	29.922		70 to 75	28.910
Singapore .	1.16	29.890		75 to 80	28.950

* It is to be regretted that, these means being the means only of the latitudes, the longitudes not being taken into account, the geographical distribution of this anomalous depression cannot yet be accurately defined.

74. The mean pressure in the equatorial regions is about 29.90; at 20° N. lat. it rises to 30.00, and at 35° N. lat. to 30.20, from which northwards the pressure is diminished. The same peculiarity is seen south of the equator, but it is not so strongly marked. At 45° S. lat. it falls to 29.90, and from this southwards it continues steadily and rapidly to fall to a mean pressure of 28.91 at 75° S. lat. This extraordinary depression of the barometer in the Antarctic Ocean, being one inch less than at the equator, and 1.326 inches less than at Algiers, is perhaps the most remarkable fact in the meteorology of the globe.

75. The pressure in the north temperate and frigid zones is in striking contrast to the above. From Athens, in a north-eastern direction, a high isobarometric line traverses Asia, passing in its course Tiflis, Barnaul, Irkutsk, and Yakutsk. To the east of the northern part of this area of high mean pressure, around the peninsula of Kamtschatka, there is a region of low barometer, the mean pressure being only 29.682. There is another remarkable area of low pressure around Iceland, the centre being probably in the south-west of the island, near Reykjavik, where the mean is 29.578. As observations are more numerous in Europe and North America, the dimensions of this depression may be defined with considerable precision by drawing the isobarometric of 29.90, which is about the mean atmospheric pressure. This line passes through Barrow Straits in North America, thence south-eastward toward Newfoundland, then eastward through the north of Ireland, the south of Scotland, and the south of Sweden, whence it proceeds in a north-easterly direction to Spitzbergen. The following mean annual pressures will show the nature of the depression:—Paris, 29.988; London, 29.956; Glasgow, 29.863; Orkney, 29.781; Bergen, 29.804; Spitzbergen, 29.794; Reykjavik, 29.578; Godthaab in S. Greenland, 29.605; Upernavik in N. Greenland, 29.732; and Melville Island, 29.807. A depression also occurs in India, where the mean is only about 29.850, whereas in the same latitudes elsewhere it is about 30.100.

76. There are thus four areas of low pressure on the globe, the extent of each being nearly proportioned to the depth of the central depression—viz., Antarctic Ocean, the least pressure being 28.910; Iceland, 29.578; Kamtschatka, 29.682; and India, 29.850; and three areas of high pressure, one lying between latitudes 20° and 40° N., another between 15° and 35° S., and the third in Central Asia, from south-west to north-east. These low mean pressures are by no means constant in all cases during the months of the year. In the Antarctic Ocean they are nearly constant during the months, with perhaps a slight tendency to an increase

in winter. In the region of low pressure round Iceland, the pressure is a little less than elsewhere in summer; but in winter, when the rainfall is heaviest, it is very much less, being 0.251 inch less in winter than in summer at Reykjavik, and 0.189 at Sandwich, in Orkney. Similarly at Petropaulovski, in Kamtschatka, the pressure in winter is 0.323 less than in summer. Hence the low mean annual pressures in the North Atlantic and the North Pacific are chiefly brought about by the low pressure during the cold months of the year, and are doubtless caused by the copious rainfall during that season. On the other hand, in Southern Asia, the lowest pressures occur in summer. Thus, at Calcutta it is 29.408 in July, while in January it is 30.102—the average pressure for that degree of north latitude. Hence, in Hindostan, the low mean annual pressure arises from the very low pressure in summer caused by the heavy rains falling at that season, particularly on the south slopes of the Himalayas. Generally the pressure is low wherever a copious rainfall prevails over a considerable portion of the earth's surface, owing to the large quantity of caloric set free as the vapour is condensed into rain.

77. It is scarcely necessary to point out how important it is to keep in mind these facts of the pressure of the atmosphere, it being evident, for instance, that a pressure of 29.00 in the North Atlantic would portend stormy winds, while the same pressure south of Cape Horn, being the mean pressure there, would indicate settled weather.

CHAPTER III.

TEMPERATURE, HOW OBSERVED AND CALCULATED.

78. The temperature of the air is ascertained by the *Thermometer*, fig. 10, which consists of a small closed glass tube, having a bulb at one end, and partially filled with mercury or spirit of wine. Of these fluids mercury is the best, owing to its uniform expansion by heat, the quickness with which, from its low specific heat, it indicates changes of temperature, and the great range of its fluidity. A spirit thermometer must be used when the temperature falls below —40°, the point at which mercury freezes. Spirit thermometers are also of great use for registering the greatest cold.

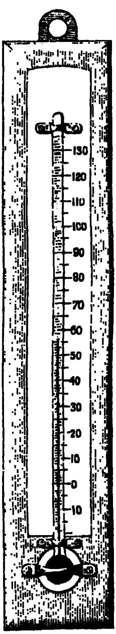


Fig. 10.

79. The following points in the construction of thermometers must be attended to. The mercury should be pure and dry, and boiled to expel the air; the bore of the tube should be equal throughout; the bulb large in proportion to the bore, that the degrees may be large and easily read; and no air left in the top of the tube. It is also most desirable that thermometers should be filled and hermetically sealed for at least a year before the scale is engraven on them. The reason is, that the fibres of the glass take some time to assume their permanent position; and since, in this transition state, the atmosphere pressing on the exterior surface of the bulb constantly tends to push the mercury further up the vacuum above the column, the result is that the bulb becomes permanently contracted in size, and the column stands higher on the scale. Nothing is more common than to find such thermometers, after being some time in use, to read 0°.5, 1°.0, or even more, too high. Owing

to the changes to which they are subject, thermometers should occasionally be compared with a standard thermometer, or have their freezing-point tested by plunging them in melting ice.

80. *Division of Thermometer Scales.*—Before the indications of different thermometers can be compared, it is necessary that there be two fixed points on their scales, each of which indicates precisely the same temperature. The points which have been chosen are (art. 8) the temperature at which water freezes, and the temperature at which it boils when the barometric pressure is 29.9 inches. In both cases distilled water must be used; for if the water contain salts or other impurities, it will freeze and boil at different temperatures. If the pressure exceed 29.9 inches, the temperature of the boiling-point will be higher, but if less it will be lower, the proportion being one degree of Fahrenheit for every 0.589 inch of pressure at moderate heights. Hence, when the barometer is 28.000, water will boil at 208.°6 instead of 212°. In Mexico, at 7000 feet high, it boils at 200°; and at Quito, 9000 feet, it boils at 194°.

81. Advantage is taken of this circumstance *to measure roughly the heights of mountains.* The temperature at which water boils is observed, from which the pressure of the air is deduced, and compared with the pressure observed at the same time at some neighbouring place, the height of which is known. From the difference of the two pressures the height is ascertained.

82. The space on the scale between these two points has been variously divided. FAHRENHEIT, a native of Dantzic, fixed the zero-point at the greatest cold then known to have occurred, in Iceland, supposing that lower temperatures would seldom require examination. The space from freezing to boiling he divided into 180 equal parts; and since his zero-point is 32 of these parts below freezing, the freezing-point of water is 32°, and the boiling-point 212°. This is the scale in common use in England and America, and its practical advantages over other scales are these: (1) the degrees are smaller than in the other scales, and (2) as the temperature seldom falls below zero, the minus sign is seldom required,—an advantage of some value in constructing and printing tables of temperature.

83. Celsius, a professor at Upsal, divided the scale between the two fixed points into 100 parts, the freezing-point being zero. This thermometer is generally called *Centigrade*, from the division of its scale into 100 parts. It is used in France and other Continental countries, and is extremely convenient for purposes of scientific inquiry.

84. In Reaumur's thermometer the same space is divided into

80 parts, the freezing-point being the zero of the scale. It is in use in Germany and Russia.

85. It is often required to convert temperatures expressed in the Centigrade or Reaumur's scale into Fahrenheit's scale, and *vice versa.* Since the space between the two standard points is divided in Fahrenheit's thermometer into 180 parts, in Centigrade into 100 parts, and in Reaumur's into 80, the proportions are—

$$F : C :: 9 : 5 \qquad F : R :: 9 : 4, \&c.$$

Hence to convert Centigrade degrees to Fahrenheit, we multiply them by 9 and divide by 5, and add 32° to the result, because 32° on Fahrenheit's scale is the zero of the Centigrade scale; and to convert Fahrenheit into Centigrade, first subtract 32°, multiply by 5, and divide by 9. In Table IV. the Centigrade thermometer is compared with Reaumur's and Fahrenheit's from 140° to —40° F.

86. *Self-Registering Thermometers.*—The most important temperatures in their relation to climates and most other inquiries, are the highest during the day and the lowest during the night; and to record these, various thermometers have been devised, well known as maximum and minimum thermometers.

87. *Maximum Thermometers.*—The maximum thermometers generally used are Rutherford's, Philip's, and Nigretti and Zambra's. *Rutherford's* has a movable steel index on the top of the mercurial column. When the instrument is in use, it is hung horizontally, and as the temperature rises, the mercury pushes the index before it, but as it falls the index is left, thus registering the highest temperature. It is set by bringing the steel index to the surface of the mercury by means of a magnet. The objection to this thermometer consists in its liability to get out of order by the index oxidising, and then getting plunged into the mercury; and so certain is it to take place in a few years at most, that the instrument cannot be recommended. The end of the index next the mercury is sometimes covered with a coating of glass, by which its tendency to oxidisation is prevented. A maximum thermometer thus constructed forms perhaps the best that has yet been invented, because the index is not easily shaken out of its position, and it may be set with a magnet without the necessity of being removed from the hook to which it is attached, thus lessening the risk of breakage.

88. In *Philip's Maximum Thermometer*, fig. 11, a portion of the mercurial column is detached and kept separate from the other part by a minute air-bubble. When in position it is hung horizontally; then as the temperature rises the whole column moves along the scale, but when it begins to fall the detached portion is

left behind at the point to which it had been pushed, thus registering the greatest heat. This is an excellent thermometer; care,

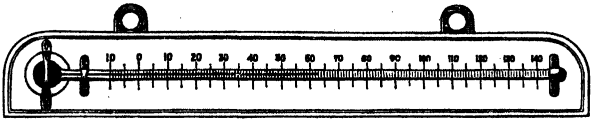


Fig. 11.

however, should be taken to select one in which the detached portion is little more than 1½ inch in length, for if it is longer, its weight in the tube makes it easily shaken out of its place, and if shorter, it is so troublesome to set, that in striking it so as to send down the detached part to the mercury, the risk of breaking it is considerable.

89. In *Nigretti and Zambra's Maximum*, the tube is bent at the foot of the scale near the bulb, and the bore of the tube contracted at the angle. It is hung horizontally; with a rising temperature the column is pushed along the scale, but when the temperature begins to fall, the column of mercury breaks at the angle where the bore is narrowed, thus leaving the mercury in the tube at the highest point to which it had been driven. It is also an excellent thermometer; but since the detached portion of mercury in the tube is always of very considerable length, and therefore of some weight, it is liable to be shifted out of its place when shaken by accident, or by the wind during storms.

90. In selecting a Philip's, or a Nigretti and Zambra's thermometer for the registration of very high temperatures, such as those recorded by thermometers exposed to the sun's rays, care ought to be taken to see that the thermometer registers sufficiently high. For these thermometers only register properly up to a certain point; the reason being, that there is almost always a portion of air, however small, in the top of the column, and hence when the mercury has risen to near the top of the tube, and the temperature begins to fall, the elastic force of the enclosed air pushes back the mercury in the tube, thus causing it to act like a common thermometer. If the mercury be heated till it rises nearly to the top of the tube, and then be allowed to cool, the height to which it registers may be ascertained.

91. *Minimum Thermometers.—Rutherford's Minimum*, fig. 12, is the best. In this thermometer the fluid used is spirit of wine, in which there is immersed a steel index. When in use it is hung horizontally. As the temperature falls, the spirit drags the index with it, but when it rises it freely passes the index and leaves it

lying at the lowest point to which it had been dragged, thus registering the greatest cold. This thermometer is set by bringing

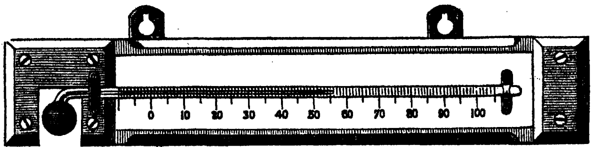


Fig. 12.

the index close up to the top of the spirit, by raising the bulb end of the instrument, or by a magnet.

92. There are no instruments for meteorological purposes so liable to go wrong as spirit thermometers, owing to part of the spirit evaporating and settling in the top of the tube. This frequently happens with spirit thermometers exposed on grass, for common purposes, outside windows; indeed I have seen them out of order to the extent of 3°, and more rarely 8°, or upwards. Such thermometers ought therefore to be frequently examined, to ascertain whether any of the fluid has lodged in the top of the tube. Spirit thermometers kept in the shade are also liable to the same derangement, but to a much less degree, because they are better protected from great heat. Generally the quantity of spirit evaporated is small, though sometimes it amounts to one degree. Observers should give special attention to this point, and the more especially so because it is by the temperature recorded by these thermometers that the chief elements of climate are determined.

93. *How to Unite the Broken Column of Spirit Thermometers.*—Fortunately spirit thermometers may be easily set right when the column of spirit chances to separate. Let the thermometer be taken in the hand by the end farthest from the bulb, raised above the head, and then forcibly swung down towards the feet; the object being, on the principle of centrifugal force, to send down the detached portion of spirit till it unites with the column. A few throws or swinging strokes will generally be sufficient, after which the thermometer should be placed in a slanting position, to allow the rest of the spirit still adhering to the sides of the tube to drain down to the column. But another method must be adopted if the portion of spirit in the top of the tube be small. Heat should then be applied slowly and cautiously to the end of the tube where the detached portion of spirit is lodged; this being turned into vapour by the heat, will condense on the surface of the unbroken column of spirit. Care should be taken that the heat is not too quickly applied, for if this be done the tube will

break and the instrument be destroyed. The best and safest way to apply the requisite amount of heat is to bring the end of the tube slowly down towards a minute flame from a gas-burner; or if gas is not to be had, a piece of heated metal will serve instead.

94. It is evident that if mercurial minimum thermometers were constructed, this source of error would be obviated. Great and partially successful efforts have been made to supply this desideratum. The *Mercurial Minimum Thermometer* of Casella may be referred to as a triumph of science and glass-blowing. It is, however, too sensitive, and the mercury too easily shaken along the tube, to be recommended for general use,—some of them being so delicately adjusted that the greatest care and most expert manipulation is required to work them. Hence the best minimum thermometers are spirit thermometers, for they really leave nothing to be desired if the most ordinary vigilance be exercised by the observer in setting them right when the column happens to separate.

95. In *Hicks's Maximum and Minimum Thermometers*, both are combined into one column; but this composite instrument is inferior to the ordinary maximum and minimum thermometers made separate from each other. This is particularly apparent in registering extreme temperatures of short duration, because the tube is filled with two fluids, mercury and spirit, having different capacities for heat.

96. No thermometer ought to be used which has not been previously compared with some standard instrument, such as the Kew standard adopted in Great Britain, so that its errors, if any, at the different points of the scale may be ascertained. This is especially necessary in purchasing cheap instruments, many of which I have had occasion to reject as being from 1° to 3° wrong. The amount of the error frequently varies at different points of the scale; thus one I compared was correct at 60°, 3° too low at 45°, and 6° too low at 32°. Errors are also found, though rarely, in first-class thermometers. Thus, I recently compared a number of high-priced thermometers, every one of which was from 1°.2 to 1°.7 too high. But it would be unjust to omit paying a well-deserved compliment to opticians for the high degree of excellence and refinement now attained in the construction of meteorological instruments. I have compared many hundreds, and could name firms, none of whose thermometers, at or above a certain price, have been found to vary from the standard more than half a degree through the scale, and many of them not more than the tenth of a degree; in other words, they might be considered as almost absolutely correct.

97. A good deal of annoyance arises from the frameworks of

thermometers being made of unsuitable materials. When any wood but well-seasoned boxwood is used, it soon warps on exposure to the weather, and the tube breaking, the thermometer is rendered useless. Porcelain scales also occasionally go to pieces, and the tubes are at the same time frequently snapped. The best frameworks are those made of zinc.

98. *Box for Thermometers.*—In order to ascertain the temperature of the air, it is necessary that thermometers be protected from the direct and reflected rays of the sun, and at the same time have the benefit of a free circulation of air. No arrangement can completely fulfil both these conditions. For if they be completely protected from solar radiation, the circulation of the air must be unduly interfered with; and if the circulation of the air is quite unimpeded, the thermometers are unduly exposed to radiation. All, therefore, that can be secured is a fair compromise between protection and circulation. The best and cheapest contrivance yet devised to meet these requirements is

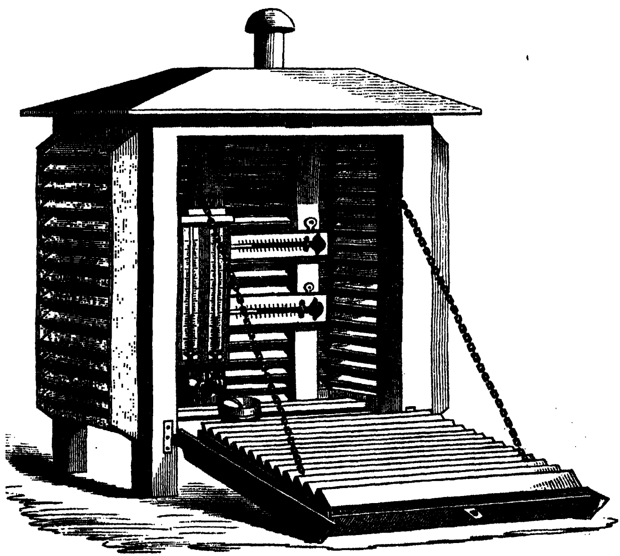


Fig. 13.

the *louvre-boarded box for thermometers*, constructed by Thomas Stevenson, C.E., Edinburgh, and now extensively used by the observers of the Scottish Meteorological Society, and other meteorologists. A figure of the box, fig. 13, is here given, with the

door let down to show the hanging of the thermometers inside. Fig. 14 shows the simple and ingenious method by which the louvre-boards are fixed.

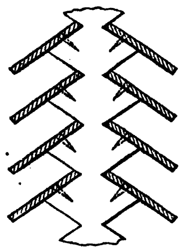


Fig. 14.

99. It is screwed to four posts firmly fixed in the ground, and these posts and the box itself are painted white, being the colour which absorbs least of the sun's heat. The posts are of such a length that when the minimum thermometer is hung in its place it is exactly four feet from the ground. This height is an essential point in the arrangements of the observatory, owing to the very great differences which frequently obtain between the temperature of the air at four feet, at the surface of the earth, and at intermediate points.

100. *Placing of the Thermometer-Box.*—The box should be placed at some distance from walls, or other objects likely to be heated by the sun; in an open space; and over old grass to which the sun has free access during the greater part of the day. For if it is placed on the north side of walls or buildings, the thermometers do not indicate a sufficiently high day temperature nor a sufficiently low night temperature for the average of the district where they are placed. And if it is placed over black soil, which is more highly heated during day, and cooled to a greater degree during night than grass, the maximum temperature will be too high, and the minimum too low.

101. *Mean Daily Temperature.*—If the thermometer be observed once each hour, or twenty-four times a-day, and the sum of the observations be divided by 24, we shall obtain the *mean temperature* of that day. Observations of this nature, extending over considerable periods, have been made at Greenwich, Leith, Rome, Madras, and other places in different parts of the world, and the hourly means for each month have been calculated and published. These tables show that there are two times in the day when the temperature is the mean, occurring generally in winter between 9 and 10 in the morning, and between 9 and 10 in the evening, and in summer about an hour earlier. Hence 9 A.M. and 9 P.M. are the hours best suited for observing when only two observations are made in the day. The means of the observations at the following hours differ very little from the true mean temperature—4 A.M., 10 A.M., 4 P.M., and 10 P.M.; 6 A.M., 2 P.M., and 10 P.M.; 7 A.M., noon, and 10 P.M.; and generally the mean of four hours at equal intervals will be found to give a result not far from the true mean.

102. When three observations are made daily, the best hours are

9 A.M., 3 P.M., and 9 P.M. The observation at 3 P.M., being near the time when the temperature is highest, is of great value in reference to the climate of the locality, as well as to other considerations of more strictly scientific interest.

103. It might have been supposed that the *daily minimum* would have occurred at the rising of the sun, or just before its rays had begun to heat the air; but observation is unanimous in showing that the minimum happens some time before the sun rises. Within the tropics, and in temperate regions during summer, it occurs about half an hour before sunrise; but in temperate regions during winter generally two hours, and at some places as much as three hours, before sunrise. As causes concerned in raising the temperature of the air before the sun's rays begin directly to influence it, may be mentioned—(1) heat reflected from the upper regions of the air, already heated as well as lighted up by the sun before it appears above the horizon; (2) heat liberated from the deposition of dew during the night; and (3) the slight influx of air from the warmer east towards the place of greatest cold, as evidenced by the daily fluctuations of the barometer, perhaps contributes in a small degree to the same result.

104. Within the tropics, and in temperate regions during winter—in other words, where the daily range of temperature is small—the *maximum temperature* occurs about an hour and a half after the sun has passed the meridian at noon. But in temperate climates during summer the maximum does not take place till from $2\frac{1}{2}$ P.M. to $3\frac{1}{2}$ P.M.

105. To this general law of the time of its occurrence there are two interesting exceptions. At many places in tropical countries it occurs about noon, or sometimes a little earlier. Thus the temperature at the coast is lowered by the sea-breeze, which begins to blow before noon, and during the rainy season the temperature at this hour is still further lowered by the clouds which overspread the sky. At the Hospice of the Great St Bernard, 8174 feet above the sea, the daily maximum temperature occurs within an hour after twelve o'clock. The air being comparatively rare at this great height, the effects of solar and terrestrial radiation are more immediately felt than at lower levels. Hence, though the heat received by bodies exposed to the direct rays of the sun at noon is very great, yet the dispersion of the heat by terrestrial radiation is so rapid that in an hour after the sun has passed the meridian, the temperature of the air begins to fall. At the Great St Bernard, at $3\frac{1}{2}$ P.M., the temperature is 1°.0 lower than it is about noon, whereas at lower situations it is from 1°.5 to 2°.0 higher.

106. In Melville Island, in the Arctic Ocean, there is no trace of a daily period during the absence of the sun in December and January; at Fort Bowen, the highest occurs in December at 9 A.M., and the lowest at 7 P.M., but at this place in January there is no trace of a daily period; at Igloolik, in North America, there is a daily fluctuation, but it is indistinctly marked. On the other hand, at Matotschin-Schar, in Spitzbergen, the daily range of temperature is well marked—the maximum during December occurring at 9 P.M., and the minimum at 8 A.M.; and during January, the maximum at 3 A.M., and two minima at 9 A.M. and 9 P.M.; or taking the mean of the whole period when the sun is invisible at this place, the maximum occurs at 8 P.M., and the minimum at 8 A.M.

107. *Mean Temperature deduced from Maximum and Minimum Temperatures.*—Of late years, since the invention of self-registering thermometers, the mean temperature has been more commonly deduced from observations of the highest and lowest daily temperatures. How far does the mean of these two represent the mean temperature? To answer this question, I have compared the mean temperature deduced from hourly observations with the mean temperature of the daily extremes at 27 places in different parts of the globe. On an average of six months of the year, the difference between the two does not exceed the third of a degree; the difference for any month seldom exceeds a degree, and the mean annual difference seldom more than half a degree. At Rio Janeiro the difference for any month does not amount to 0°.3, whereas at Catherinenburg, in the Ural Mountains, it exceeds this amount in every month but one. In some places the differences are all in excess, in others they are all in defect; in some places an excess occurs in winter and a defect in summer, and in other places *vice versa*. In most places the great difference is in October and November, but in a few places the reverse holds good.

108. Comparing the Leith and Greenwich observations, we find that the mean annual deviation at Leith is 0°.2, at Greenwich, 0°.7; the lowest monthly deviation at Leith, 0°.1, and at Greenwich, 0°.2; and the highest at Leith, 0°.6, and at Greenwich, 1°.1. It would appear that these differences are dependent almost entirely on local peculiarities, such as the open or confined situation of the thermometers, the covering of the ground over which they are placed, the protection from radiation, and the degree of freeness with which the air circulates around them.

109. At the stations in connection with the Scottish Meteorological Society, the mean of the daily extremes is accepted as the

mean temperature, and most meteorologists now adopt the same mean. Others, however, apply to this mean a correction in order to bring it to what is conceived to be the true mean temperature. This is a practice which for many reasons ought to be discouraged. The mean of the daily extremes gives observation alone; whereas the "corrected" means are vitiated by misleading hypotheses. If an observer in the north of England gives the "corrected" mean temperature of August 1865 as 57°.3, what does this mean? If he has adopted the Greenwich correction for that month, the observed mean was 58°.2, but if the Leith correction it was 57°.4. If two observers near each other should use the one the Leith correction and the other the Greenwich, a difference in the climates of the two places would be indicated which has in reality no existence.

110. *Value of Extreme Temperatures.*—Self-registering thermometers are of great practical value in recording the extreme temperatures, which in reference to their effects on health and vegetation must be regarded as most important elements of climate. The subject of extreme temperatures is one of paramount importance, especially where the transitions of temperature are sudden and violent. In the north-western parts of the United States of America the temperature in spring often rises to 83° during the day, and falls to freezing during the night. Under such a climate the vital functions of plants whose tissues abound in sap are called into activity during the day, but this sap being frozen during the night, the vessels containing it are ruptured by expansion, and the plant, if not totally destroyed, is so seriously injured that its successful cultivation becomes precarious and uncertain. The same risk is not incurred in such places as Great Britain, where the seasons shade into each other by nice and almost insensible gradations. It is, however, everywhere desirable to arrive at some definite information as to the probability of occurrence of certain extreme temperatures that may take place in the different seasons, and this can only be done by observations of extremes carefully made and recorded from day to day.

111. *Importance of resolving Mean Temperature into the Extremes which compose it.*—Every mean temperature may be considered as a composite element, made up of the mean temperature of the day and the mean temperature of the night. Hence the same mean temperature often stands for two things essentially different. Thus, Madrid in the centre of Spain, and Menton on the Gulf of Genoa, had the same mean temperature of 72°.8 during September 1865. But the climates of the two places

were widely different ; for the temperature at Madrid during the warmest period of the day was on an average 86°.2, whereas at Menton it was only 77°.6 ; and during the coldest period of the night it was 59°.5 at Madrid, whilst at Menton it was as high as 68°.0.

112. Again, in the same country and in the same month, but in different years, the same mean temperature when resolved into the extremes that compose it represents very different things. Thus, the mean temperature of Scotland in August 1860 was 54°.4, and in the same month of 1864 it was also 54°.4 ; but in 1860 the mean of the highest day temperatures was 60°.8, whilst in 1864 it was 62°.5. This higher day temperature in 1864 was the chief cause of the productive harvest of that year, and the lower day temperature of 1860 was the chief cause of that year's deficient harvest, and yet the mean temperature of both years was the same. Thus, in considering the relations of mean temperature to health or agriculture, it is most essential to know the separate elements which make up the mean temperature.

113. *Range of Temperature.*—This points out the importance of considering the daily range of temperature, or the difference between the extreme day and night temperatures. Additional interest is added to the subject by the consideration that the rate of mortality is to a very large extent determined by the range of temperature of the climate. Everywhere it is least in winter, augments rapidly in March and April, reaches the maximum in May or June, continues high during summer, and diminishes rapidly in October and November to the minimum in the winter months. As regards climates, it is least in wet climates, and in the tropics and polar regions ; and greatest in dry climates and in temperate countries. Hence it is less in Ireland than in Scotland, greater in England than in both these countries, and still greater on the continent of Europe. In Shetland, Orkney, and the Hebrides, whose climates are perhaps the most strictly insular in Europe, the summer range is only about 10° ; on the west of Great Britain it rises to 12° and 14° ; and in the central districts to 15° ; and in the south to 20°. At Paris, Utrecht, Vienna, and other places on the Continent, the range is still higher. In the dry climate of Jerusalem, in Syria, it amounted to 23° in four months of 1864 ; in the still drier climate of Madrid a range of 27°, and in one month 31°, was observed in 1865. A similar high range is frequently recorded in the Russian and Siberian steppes. At Trevandrum, in Southern India, during the dry season in January, the daily range is about 17°, but during the rainy season in July it is only half that amount. The greatest

monthly differences are observed in the polar regions. Thus, in Spitzbergen and Boothia Felix, the range in winter varies from 1° to 0°; in May, when the sun has reappeared and continues to rise and set, it is about 14°; but in July, when the sun does not set, the range is only 10°.

114. But in comparing climates there is not a more misleading element than range, unless care be taken to be informed of the circumstances under which the range was obtained. Thus, in the above instances the term has been employed to signify the difference between the mean of the maximum and the mean of the minimum temperature, at whatever hour these may chance to happen from day to day. This is the true daily range of temperature. In some books, however, the daily range of temperature means the difference between the mean of the coldest and the mean of the warmest of the twenty-four hours, and is therefore always less than the former. Owing to the restricted use of self-registering thermometers over the earth, the latter of these two is more widely known than the former.

115. Again, the amount of the range depends to a great extent on the degree to which the thermometers are protected from, or exposed to, direct and indirect radiation, and also to their height above the ground. For if the louvre-boarded box is behind a wall to which the sun has little or no access, the range will be several degrees less than if it was in an open situation on which the sun shines during most of the day; the range will be greater over black earth than over grass; greater over long grass than over short grass; greater with than without a proper ventilation to the box; greater the more the louvre-boards are apart; greater if the box is always kept open to the north than if louvre-boarded all round; and greater the nearer the thermometers are to the ground. Hence the extreme desirableness of uniformity of observing in all parts of the world. It may be noticed here as remarkable, that in most of the above cases, though the range differs greatly, yet the mean annual temperature is found to be nearly the same.

116. Of the daily registered highest and lowest temperatures, the following, for July 1866, is a specimen of the monthly abstract published by the Scottish Meteorological Society, as regards Edinburgh:—

	Degrees.
Highest temperature in month, . . .	82.7
Lowest do. in month, ...	45.0
Monthly range, ...	37.7
Greatest daily range, ...	29.7
Mean of all the highest	65.5

	Degrees.
Mean of all the lowest, ...	51.5
Mean daily range, ...	14.0
Mean temperature, ...	58.5

117. The above analysis continued from month to month through a number of years, is sufficient as a basis on which the main element of climate may be established. But there are other points of the greatest practical importance in climate which require a more searching analysis for their elucidation, such as the frequency of occurrence at different seasons of certain temperatures exercising a powerful influence on vegetation and on health.

118. The most important question in connection with low temperature is *the occurrence of frost.* Both to the farmer and to the physician it is of the utmost moment to know how often and with what severity frost may be expected to occur, and when for all practical purposes it ceases to occur, or happens so seldom as to cause no alarm, and call for no precaution on the part of those whose interests may be affected by it. On the other hand, the question to be inquired into in an investigation of high temperatures as affecting agriculture, is not so much injury received as advantage gained by their occurrence. The growth and maturing of crops depend chiefly on the heat they receive from the sun. And in countries such as Scotland, whose temperature but barely exceeds the minimum heat required for the proper ripening of the staple objects of agriculture, the inquiry becomes invested with a peculiar interest, especially in examining places and localities differing in latitude, proximity to the sea, exposure, and elevation. As regards Great Britain, if the day temperature rises occasionally to 65°, the degree of heat thus received by the grain crops may be looked upon as sufficient for their growth up to the period of flowering; but after this a higher temperature is required, and a frequent day temperature of 70° is necessary to produce the finer qualities of wheat and barley. For other countries different temperatures would require to be investigated—namely, those essential to the successful cultivation of their staple products.

119. In order to render tables of this description practically as well as popularly useful, the occurrence of the critical temperatures should be given separately for every week of the year. Little has yet been done in preparing such tables, owing to the heavy tedious labour in compiling them. Perhaps Scotland is the only country whose climate has been thus examined; it is to be hoped that observers in other countries may be induced to publish the results of their own observations. In this way a storehouse of the most valuable information would be collected, by which agri-

culturists might arrive at a knowledge of the character of the climate they have to deal with; and by which physicians might reason with more certainty than at present regarding the spread of diseases, the rates of mortality peculiar to different countries, and the places to which invalids may be sent, so as to enjoy the greatest safety or receive the most advantage that can be procured from a change of climate.

CHAPTER IV.

TEMPERATURE—SOLAR AND TERRESTRIAL RADIATION.

120. THE interchange of temperature among bodies takes place by conduction, convection, and radiation.

121. *Conduction.*—The communication of heat by *conduction* proceeds from particle to particle, and implies contact with, or very near approach to, a hotter body. As a class, metals are the best conductors; solids are better conductors than liquids, and liquids better than gases, which are the worst conductors.

122. The most important illustrations of conduction in meteorology, are the propagation of the changes of temperature downwards through the earth's strata from the surface as it is heated during the day or cooled during the night; and the communication of the same changes of temperature to the lowest stratum of the atmosphere resting on the surface. As regards the relative conducting powers of different substances, dense soils, or soils having their particles closely packed together, are much better conductors of heat than loose porous soils, because the latter imprison large quantities of air in the interstices between the particles, thus diminishing the conducting power of the soil. From this it follows that light loose soils are subject to higher temperatures, and to a greater degree of frost, *near the surface*, than dense heavy soils; but, on the other hand, frosts and extreme temperatures do not penetrate so far down into light as into heavy soils. In Scotland, during the past nine years the temperature at three inches below the surface has fallen to 26°.5 in loose sandy soils, and at a depth of twelve inches the freezing-point has only once been observed. But in clay soils, at three inches the lowest is 28°, whilst at twelve inches the temperature often falls to freezing, and even at twenty-two inches 32° has once been recorded.

123. Damp air is a much better conductor of heat than dry air. Damp air consequently feels colder than dry air of the same temperature, because it takes away the heat from our bodies more

rapidly. Thus at the breaking of the severe frost which prevailed in Great Britain in December 1860, when the temperature had risen to 32°, the air being moister, the weather was more disagreeably chilly than when the temperature was below zero.

124. Snow being composed of crystals, with a very large quantity of air entangled among their interstices, is on that account one of the worst conductors of heat. It thus serves to protect the soil in winter in two ways—(1) it prevents the escape of heat from the earth to the air; and (2) it sets a limit to the depth to which severe frosts penetrate, thus protecting the roots of plants from injury.

125. *Convection.*—Though fluids and gases are bad conductors of heat, yet they may be quickly heated by a process of circulation of their particles called *convection.* When heat is applied to the bottom of a vessel containing water, the particles at the bottom, being heated, become lighter and rise to the surface, and other particles descend to take their place. Thus two currents are formed, the hotter ascending through the centre of the vessel, and the colder flowing down the sides. This circulation continues until the whole of the water attains the same temperature.

126. The communication of heat by convection is seen on the most extensive scale over the globe in the winds and in the currents of the ocean. We see it in the ascending and descending currents of the atmosphere everywhere, which are caused by the daily fluctuations of temperature on the surface of the earth; for when the surface is heated by the sun, the air immediately resting on it becomes heated and ascends, and colder particles descend to occupy its place. Under the tropics the air becomes highly heated, ascends and flows off towards the poles, whilst colder currents flow from the poles to the equator, giving rise to the polar and equatorial currents of the atmosphere. The same cause puts in circulation the waters of the ocean. The great and beneficial effect resulting from these currents is a more equal distribution of temperature, thereby mitigating the rigours of the polar cold, and moderating the scorching heat of the tropics.

127. *Radiation.*—An interchange of heat is constantly going on among bodies freely exposed to each other, whether their temperature be the same or different from that of the bodies which surround them. If we stand before a fire we feel the influence of its heat, though at some distance from it. This mode by which heat is communicated is called *radiation.* Radiant heat proceeds in straight lines, diverging in all directions from its source, is only to a limited extent affected by the air through which it passes, and is not diverted from its straight course by the wind. Its in-

tensity is proportioned to the temperature of the source, is inversely as the square of the distance from the source, and is greater according to the degree of inclination of the surface on which the rays fall.

128. If a body be placed in the presence of other bodies, some colder and some hotter than itself, it will from this mutual interchange of temperature receive more heat from the hotter bodies than it radiates to them, and thus become warmer; but it will receive less heat from colder bodies than it radiates to them, and consequently become colder. This is the condition in which the earth is placed. When its surface is turned towards the sun, it receives more heat than is radiated from it; but when it is turned from the sun towards the cold regions of space, it gives out more heat than it receives. These two conditions under which the earth is placed are so essentially distinct that the subject of radiation falls naturally under two heads—viz., *solar radiation* and *terrestrial radiation.*

129. Solar Radiation.—(1.) *On Land.*—Of the solar heat which arrives at the surface of the earth, the part which falls on land is wholly absorbed by the thin superficial layer exposed to the heating rays; and since there is no mobility in the particles of the land, the heat can be communicated downwards only by conduction. While the temperature of the surface increases, a wave of heat continues to be propagated downwards through the soil. The intensity of the daily wave of temperature rapidly diminishes with the depth—the rate of diminution depending on the conducting power of the soil—until at about four feet from the surface it ceases to be perceptible.

130. As regards the effect of the solar heat on the temperature of the air, it is the temperature of the extreme upper layer of the land which requires almost exclusively to be considered, seeing it is chiefly by contact with the surface that the temperature of the air is increased or diminished. Hence it is badly conducting surfaces which have the greatest influence in raising the temperature of the air. The surface temperature of the sandy deserts of the tropics frequently rises to 120°, 140°, and, more rarely, 200°. When these hot particles of dust are lifting into the air by the winds, the temperature of the air itself has been known to rise to 125° in the shade; and it is this which gives the sirocco and simoom of the desert their dreaded name. It is in the deserts of Africa and Arabia where the highest temperature on the globe occurs, their mean summer temperature ranging between 92° and 95°. The surface of loam and clay soils is not heated to so high a degree as sandy soils,

and the surface of rocks to a less degree, because, being better conductors, the heat is not left to accumulate on the surface, but is more quickly propagated downwards.

131. When the earth is covered with vegetation, the whole of the solar heat falls on the vegetable covering; and as none of it falls on the soil, its temperature does not rise so high as that of land without any covering to protect it. The temperature of plants exposed to the sun's rays is not so high as that of the soil under the same circumstances, partly because a portion of the solar heat is lost in the process of evaporation from the pores of the plants, and partly because the heat is not allowed to accumulate on the surface of the plants as it does on the soil. For the leaves being thin, and the greater part of their substance being on that account in immediate contact with the air which envelops them, they are quickly robbed of their superfluous heat; and owing to the levity of heated air, it is constantly flowing off and giving way to colder air to supply its place. Hence one chief difference between the climates of two countries, the one covered with vegetation and the other not, is, that the heat, being more distributed over the twenty-four hours in the former case, is less intense during the hottest part of the day.

132. *Influence of Forests on Climate.*—The effect of vegetation in changing the mode of the distribution of the daily temperature is most strikingly illustrated in the case of forests. Trees are heated and cooled by solar and nocturnal radiation in the same manner as other bodies. They do not, however, acquire their maximum temperature till a little after sunset. This occurs in summer at 9 P.M., while in the air the maximum temperature occurs between 2 and 3 P.M. Hence trees may be conceived as reservoirs in which the heat of the day is stored up against the cold of the night. Changes of temperature take place very slowly in the tree, but in the air they are very rapid. Hence the effect of forests on the daily temperature is to make the nights warmer and the days colder, or to give to the climate of countries clad with trees something of the character of an insular climate. Evaporation goes on slowly from damp ground under the trees, being screened by them from the sun's heat. But since the air among the trees is little agitated or put into circulation by the wind, the vapour which arises from the soil is mostly left to accumulate above it. Hence, though exact observations are wanting to settle the question, it is probable that forests diminish the evaporation and increase the humidity. It also follows that forests diminish the summer temperature, and maintain the winter temperature higher than it would otherwise be. This enables us to

understand how forests increase the rainfall. For suppose an extensive forest to lower the summer temperature of a district to the extent of about 2°.0, the effect on the rain-bringing winds would be much the same as if a low range of hills opposed their course, and condensed their vapour into rain.

133. The valley of Aragua, in Venezuela, is shut in on all sides, and the rivers which water it, having no outlet to the sea, unite and form Lake Tacarigua. This lake during the last thirty years of the past century showed a gradual drying up, for which no cause could be assigned. In the beginning of the present century the valley became the theatre of deadly feuds during the war of independence, which lasted twenty-two years. During that time land remained uncultivated, and forests, which grow so rapidly in the tropics, soon covered a great part of the country. In 1822 Boussingault observed that the waters of the lake had risen, and that much land formerly cultivated was at that time under water. The drying up of the river Scamander in the Troad, and the contracting of the Euphrates in its channel, may be referred to as illustrations of the same effect of the cutting down of forests.

134. (2.) *On Water.*—When the solar heat falls on water, it is not, as in the case of land, arrested at the surface, but penetrates to a considerable depth below the surface. Also, since water is a bad conductor, the heat cannot penetrate lower down by conduction as it does through land, but can only be communicated by the agitation caused by currents or winds. Thus the heat received daily by the ocean is diffused through a considerable depth of the water floating near the surface.

135. *Specific Heat of Water in relation to Climate.*—The specific heat of a substance is the number of units of heat required to raise the temperature of one pound of it by one degree. Thus the same amount of heat that will raise one pound of water one degree will raise one pound of mercury 33°. If therefore we call the specific heat of water 1000, the specific heat of mercury is only 33. Of all known substances water has the greatest specific heat. As compared with the specific heat of the soil and rocks which compose the earth's crust, it is in the proportion of about 4 to 1. It follows that the surface of the sea cannot be raised to nearly the same degree of heat by the sun's rays as that of the land; and that when the temperature is falling, the sea cools very much more slowly than the land. Thus, while the surface temperature of the soil has been frequently observed to be as high as 140°, the surface of the sea has in only a few cases been observed to exceed 85°. It is to the great specific heat of water

that the enormous effects of the ocean in modifying climate are chiefly due.

136. The temperature of the sea is also diminished by the process of evaporation constantly going on from its surface.

137. *Mode of Observing the Temperature of the Surface.*—It is necessary to distinguish between the amount of solar heat which arrives at the surface of the ground, and the temperature to which the surface is raised by the heat which thus falls upon it. But it is only with the temperature of the surface that as practical meteorologists we have to do. In attempting to ascertain the effect of this element on the climate of such a country as Great Britain, which has so large a portion of its surface covered with grass or analogous plants, it is evident that it is to the temperature of grass that we should direct our attention. In vine-growing countries, where a great part of the surface of the soil is exposed to the sun, and in countries whose surfaces consist of rocks or tracts of sand destitute of vegetation, the temperature of the surface exposed to the solar heat will be very different from that of Great Britain. Care should be taken to place the thermometer in positions which will enable the observer to ascertain the temperature of the general surface. The temperature to which the leaves of plants, the ears of wheat, and other objects of agricultural and horticultural produce, are raised by the direct rays of the sun shining on them at different heights and in different climates, though a subject of great practical importance, has not yet been inquired into.

138. The instrument used in observing the temperature of the surface is a *maximum black-bulb thermometer*, which is an ordinary maximum thermometer, having its bulb covered with a thin coating of lamp-black, and quite exposed to the sun and air. It should be placed horizontally over short grass, so near the ground as just to be above the grass, and in such a position that the sun shall shine directly on the bulb for as large a portion of the day as possible. This is best accomplished by making the bulb project a little beyond the framework of the thermometer, and point directly to the sun at twelve o'clock. It is only by attending to such directions as these that any tolerable uniformity can be obtained among black-bulb observations. Observations do not admit of comparison where the exposure and duration of exposure of the bulbs of the thermometers to the sun, their height above the surface, and the character of the surface, are different.

139. It frequently happens in cloudy weather, when there is mist or drizzle, that these exposed black-bulbs register a lower temperature than thermometers in shade, being for the time al-

most under the conditions of the wet-bulb thermometer. But in such cases the difference is always small. Again, during calm, foggy or dull weather, suddenly following cold, such as frost in winter, it often happens that the exposed maximum thermometer is several degrees lower than the protected one—a difference due to the proximity of the exposed thermometer to the cold ground.

140. *Black-bulb thermometers* enclosed in thin glass tubes, hermetically sealed, are used for the purpose of ascertaining approximately the amount of the solar heat falling on the surface of the earth.

141. Terrestrial Radiation.—Since the mean temperature of the earth remains practically the same, it is evident that the earth must part with the enormous quantity of heat which is poured on it from the sun from day to day. It is by its own radiation into space that the earth parts with this heat,—a process which is continued by day as well as by night. During the day the heat radiated from the earth is less than that received from the sun, and as long as this continues the temperature rises. But as the sun sinks near the horizon, its beams falling more aslant, less heat begins to fall on the earth than is given off by radiation. For a time the loss thus sustained by the surface temperature is compensated for by heat rising to the surface from the heated strata immediately below it. This mode of making up the loss lasts only a short time, because the escape of heat by radiation is much more active than the propagation of heat by conduction. As soon, then, as the radiation from the surface exceeds all sources of supply, the temperature begins to fall, and continues to do so till it is arrested, or till the sun again returns. When the chilling of the surface goes on, it receives additions of heat from the air in immediate contact with it, and from the air above by radiation downwards from it. Since, then, during night, and during the winter, the cooling of the air is brought about by contact with the chilled surface of the earth, it follows that up to a certain elevation the temperature of the air will increase with the height.

142. There is another source from which the chilled surface receives accessions of heat, viz., when the air at the surface is cooled down to the temperature of the dew-point; for when this point is reached dew is deposited, and latent heat is given out, as happens in every case when gaseous bodies are converted into fluids.

143. When the sky is wholly or partly covered with clouds, a large part of the heat radiated from the earth to the clouds is radiated back again by the clouds to the earth; and thus on

cloudy nights the loss of heat by radiation is not so great as on clear nights, and not so great when the clouds are low as when they are high.

144. But the vapour of water obstructs radiation, not only when in a visible form as clouds, but also when it is diffused in an invisible state through the air; and hence the drier the air is, the colder is the temperature during night.

145. The surface of the earth is cooled by radiation to a greater degree during calm than during windy nights, because, owing to the agitation caused by the wind, it is warmed by contact with the air of the upper as well as of the lower strata of the atmosphere. The amount of heat radiated is the same, but the effects are not, as on calm nights, chiefly confined to the surface, but are more generally diffused through the air itself.

146. The degree to which the temperature of any object is reduced by radiation, is proportioned to the amount of sky exposed to the free view of that object. Thus if houses or trees be near—that is, if they cut off a part of the sky from the field of view—the temperature will not fall to the same extent. The degree to which this remark holds is very striking when first brought under the notice of an observer. A sensitive mercurial thermometer will be seen to rise at once by the heat radiated from his person, as he approaches to examine it. Nay, even the holding up of the fragment of a wooden rail at a distance of some yards from the thermometer, has been observed perceptibly to raise its temperature. A cloud passing over raw wool much cooled by radiation, has been observed by Mr Glaisher to raise the temperature of the wool 1° per minute, and 15° in the quarter of an hour.

147. *Means of Measuring the Cold of Radiation.*—A thermometer is exposed in the focus of a concave mirror, polished within and without, with the concavity pointing upwards, in order to cut off all view of the earth. The only heat a thermometer placed in these circumstances can receive, is from the radiation of the air, and from the condensation of moisture. A thermometer so exposed always indicates a lower temperature than thermometers exposed on the surface of the earth.

148. But since it is the temperature of the surface of the earth which it is most important to know, owing to its intimate connection with the temperature of the air, a much simpler instrument is adopted. This is the ordinary *minimum black-bulb thermometer*, which is a common minimum thermometer with its bulb blackened. As in the case of the maximum black-bulb, it is laid on grass with its blackened bulb freely exposed, and in such a position as to command a view of the whole of the sky, or as much of

it as possible. If it does not command a view of the whole, the amount cut off by surrounding objects should be noted. It should always be placed just above the ground, never on an object at some height above the surface; it should also be laid on grass kept short; and the blackened bulb should project a little beyond the scale, so as to be freely exposed all round. The reason for these restrictions will soon appear.

149. The degree to which the temperature falls depends on the radiating and conducting powers of the surface over which the thermometer is placed, being greater as the radiating power is greater and the conducting power less, and *vice versâ*. We give below the relative cooling powers of a few of the more important substances determined by Mr Glaisher, from experiments made by him,—long grass being 1000:—

Hare skin,	1316	Glass,	864
Raw white wool,	1222	Snow,	657
Flax,	1186	Garden mould,	472
Raw silk,	1107	Sand,	454
White cotton wool,	1085	Stone,	390
Lamp-black powder,	961	Gravel,	288

150. One of the most instructive examples illustrative of this subject that could be given is the result of Mr Glaisher's observations on the different temperatures of long and short grass. A thermometer placed on long grass was found to be on a mean 1°.1 lower than one on short grass, whilst the temperature of the soil under long grass was 1°.1 *higher* than under short grass. The temperature was thus the same amount in excess under the long grass as it was in defect over it. Hence the difference of temperature over the long and the short grass was entirely due to the greater quantity of heat conducted from the soil to the top of the short grass over that conducted to the top of the long grass, and not to any difference in the radiating powers of the grasses. The experiments were extended, and it was found that the temperature varied with every variation of length, fineness, and closeness of texture of the blades of the grass.

151. We thus see why it is that the temperature of grass and other plants falls during the night so much below that of garden mould, sand, and gravel. The great difference is not owing so much to different quantities of heat radiated into space, but to the ease or difficulty with which heat is conducted from the soil to the radiating surfaces so as to supply the loss sustained by radiation.

152. *Dew.*—When a glass of cold water is brought into a warm room the surface of the glass is soon covered with small globules

of water, provided the temperature of the water be *below* the dew-point of the air. This phenomenon takes place on a grand scale over the earth's surface on every night when the atmosphere is comparatively clear and calm. For, as the earth is cooled down by radiation, as soon as the temperature of the dew-point is reached by any body, the vapour of the air begins to be condensed into dew on its surface. The quantity of dew which is deposited is in proportion to the degree of cold produced. Hence, from what has just been said in article 149, more dew will be deposited on furs, wool, silk, flax, and cotton, than on grass and vegetable substances generally, and less on glass, mould, sand, and gravel. Thus, by a most beneficent arrangement, dew falls most copiously on the objects on the earth's surface which most require its refreshing influence. It is not deposited in cloudy weather, because the clouds obstruct the escape of heat by radiation into space ; nor in windy weather, because wind constantly renews the air in contact with the ground, and thus prevents the temperature from falling sufficiently low. No dew is deposited on the surface of deep water, because its temperature scarcely ever falls below the dew-point. When the temperature is below the freezing-point, the dew freezes as it is deposited, and *hoar-frost* is produced. See art. 13.

153. *Effects of Radiation on Water.*—Water being a good radiant, heat is freely given off from its surface as well as from land. But from various causes the effects of radiation on the surface of water are very different from those on land. Owing to its great specific heat, its temperature falls much more slowly than that of land. This conserving influence of water on the temperature is greatly increased by another peculiarity. For when the particles floating on the surface are cooled by radiation they become heavier and sink, and warmer particles from below rise to supply their place. Thus the surface can only cool as the entire body of water is cooled, and the change of temperature occasioned in a body of deep water by radiation from the surface during a night will be almost imperceptible ; consequently the temperature of the air resting on this water will undergo comparatively little depression on calm nights.

154. The descent of the cold, and ascent of the warm, particles of water, is a much slower process than is generally supposed. From observations made by Captain Thomas during September and October 1858 and 1859—that is, during the great annual fall of temperature—it was found that the mean temperature at a depth of 24 feet was 1° *warmer* than at 1 foot, and about 0°.8 warmer at 60 feet than at 6 feet. This is instructive, and shows the value of observation over theoretical deductions; for theory might have

led us to suppose that the warmer water would have risen more readily to the surface. At this season the water of the sea is not in a state of equilibrium, a disturbing agent being at work, the cooling of the surface water, causing a continual descent of the colder and ascent of the warmer particles; and this process goes on as long as the surface is colder than any of the underlying watery strata. The difference between the temperature of the surface and that at several fathoms below the surface, shows, in a forcible manner, the length of time required to effect a complete correspondence between the temperature of the sea and that of the air; for, being brought about by upward and downward currents, the difference of whose temperature is small, the motion of the currents and the interchange of temperature resulting therefrom proceed at a very slow rate.

155. The mean daily range of the temperature of the sea has been ascertained off the Scottish coast from Captain Thomas's observations, already referred to. On a mean of the year it is as follows:—

Mean of daily Minima .	48°.43	Maximum at 4 P.M. .	49°.02
Mean at 11.20 A.M. .	48°.89	Mean at 1.20 A.M. .	48°.89

Hence the temperature of the sea near the surface only varies on the average about 0°.6 in the day, while in Scotland the air varies 12° on the average. The greatest differences observed on any day in the temperature of the sea were 5°.6 and 5°.3, amounts especially exceptional, whilst the temperature of the surface of the land varies not unfrequently as much as 100°. These figures present in perhaps the most striking light the conserving influence of the ocean on climate.

156. It is a well-known law of matter that bodies expand with heat and contract with cold; but to the law water is one of the remarkable exceptions. Water follows this natural law till it falls to 39°.2, after which, as the temperature falls, instead of contracting it begins to expand, and continues to do so till it reaches the freezing-point. Water is, therefore, at its maximum density at 39°.2. When it is just falling to 32°, or immediately before it freezes, it occupies as great a space as it did at 48°. But if common salt be dissolved in water, the temperature of its maximum density is lowered; and if it be brought to the average degree of saltness of sea-water, its maximum density would be 27°.2, if it did not freeze before reaching that point.

157. Since, then, sea water follows the general law in contracting as it is cooled till it freezes, no ice can be formed on its surface till the temperature has fallen through all its depths nearly to freez-

ing. On the other hand, as soon as the temperature of fresh water has fallen to 39°.2 through all its depths, the surface-water becomes lighter as it gets colder, and consequently no longer descends, but floats on the surface. This circumstance marks an essential distinction between the effects of sheets of salt and fresh water respectively on climate. The surface temperature of sea-water falls very slowly from 39°.2 to 32°, because as it falls the temperature of the whole water through its depths must be reduced, whilst from 39°.2 to 32° the surface temperature of fresh water falls rapidly, because it is only the portion floating on the surface which requires to be reduced.

158. *Difference of Shallow and Deep Lakes on Winter Climates.*—Owing to its great depth, Loch Ness, in Inverness-shire, is not known to freeze. Its temperature being therefore always high, even during intense and protracted frosts, the winter climate along its shores is mild and partially insular in its character. So high is the temperature of the lake that the Ness does not freeze in its short course to the sea ; thus presenting so remarkable a contrast to the ice-bound streams on each side, that an oily element is vulgarly attributed to its water, preventing it from freezing. On the other hand, Loch Leven, in Kinross-shire, being shallow, is easily frozen over, and hence it has no effect whatever in moderating the rigours of intense frosts on its banks.

159. As these lakes are small, their influence operates but to a very limited extent. It is in the magnificent system of fresh-water lakes in North America that this influence is most strikingly displayed. Owing to the severity of the winters these lakes are frozen over during that season, and hence that region is curiously characterised by a winter climate of continental severity, and a summer climate of comparative insular coolness.

160. Advantage has been taken of terrestrial radiation *in the formation of ice* during the night in Bengal when the temperature of the air is above 32°. The process was first described by Sir R. Barker, and afterwards by Mr Williams. It was a profitable business, and three hundred persons were employed in it. A piece of ground, nearly level, was divided into square plots, from 4 to 5 feet wide, which were surrounded by little mounds of earth, 4 inches high. In these enclosures, previously filled with dry straw or canes, many broad shallow unglazed earthen pans were placed, containing pump-water. When the air was still much ice was formed ; wind prevented its formation altogether. The object of the excavations and little mounds of earth was to increase the stillness of the air. Since, then, the evaporation must have been small when ice was formed most plentifully, the cooling of the

water and the formation of the ice was caused by terrestrial radiation. The object to be obtained in using dry straw was to secure for the pans a badly conducting substance; when the straw was wetted, and its conducting power thus increased, little or no ice was formed.

161. *Effects of Terrestrial Radiation on Land.*—One of the chief effects of terrestrial radiation on the air superincumbent over land, as compared with that over the sea, is to increase the range of the temperature. Thus, while the mean daily variation in the temperature of the air over the sea in the west of Scotland is about 6°.0, on the land it is about 12°.0; and in extreme cases the variation on land is three or four times the variation on the sea.

162. *Increase of Temperature with the Height during Cold Weather.*—This takes place invariably in dry, calm, clear weather, during the night, and in winter, when the temperature of the air falls by contact with the chilled surface of the earth. Between the temperature of the air in contact with the surface of the ground, and the air 4 feet above the ground, the difference is frequently 15° or 20° during the night, but above 4 feet the differences are comparatively small. On the 8th April 1844, at 8 P.M., Mr Glaisher observed a difference of 25°.0 between two thermometers, one placed on raw wool over long grass, and the other at a height of 4 feet; and at 8 feet high the temperature was 3°.5 warmer than at 4 feet. Hence the temperature of the air on the ground was 28°.5 colder than at a height of 8 feet at the same time. From an extensive series of observations made by the same indefatigable meteorologist with thermometers fully exposed to the sky, the means, as compared with those *on long grass*, were as follow:—

At	1 inch	above long grass	+ 2°.76
,,	3 inches	,,	+ 4°.39
,,	6 ,,	,,	+ 6°.02
,,	12 ,,	,,	+ 7°.31
,,	24 ,,	,,	+ 7°.67
,,	48 ,,	,,	+ 7°.81
,,	96 ,,	,,	+ 8°.26
,,	144 ,,	,,	+ 8°.27

A thermometer at 4 feet above long grass, protected from six-tenths of the sky, stood, on a mean, 8°.39 higher. Hence the necessity of having all thermometers in shade placed at the same height above the ground, for otherwise the results are not comparable. From experiments made by M. Ch. Martins in the south of France, he found, on a mean of 88 nights, that the temperature at a height of 6½ feet as compared with 2 inches, was 1°.5 warmer;

that for every yard between 20 and 96 feet, it was 0°.12 warmer, and between 96 and 162 feet, it was 0°.04 warmer.

163. But the rate at which the temperature increases with the height, is modified to a very great extent by the physical configuration of the surface—that is, whether that surface be level, undulating, or mountainous. To understand how this happens, let us suppose an extent of country diversified by plains, valleys, hills, and table-lands, to be in circumstances favourable to radiation, and each part under the same meteorological conditions, except in the single point of position. Radiation will proceed over the whole at the same rate, but the effects of radiation will not be felt everywhere in the same degree and intensity. For as the air in contact with the declivities of hills and rising ground becomes cooled by contact with the cold surface of the ground, it acquires greater density and weight, and consequently slips down the slopes and accumulates in the plains below. Hence places situated in plains and rising ground are never exposed to the full intensity of frosts ; and the higher they are relatively to the surrounding ground, the less are they exposed, because they are protected by their elevation providing, as it were, an escape for the cold almost as fast as it is produced. On the contrary, valleys more or less environed by hills or eminences, not only retain their own cold of radiation, but also serve as reservoirs for the cold of neighbouring heights. Hence low-lying places are peculiarly exposed to intense cold. Plains and table-lands are simply affected by their own radiation.

164. This explains why vapour becomes visible so frequently in low places, whilst adjoining eminences are clear ; and the same fact instinct has made known to cattle and sheep, which generally prefer to rest during night on knolls and other eminences. Along most of the watercourses of Great Britain, during the memorable frost of Christmas 1860, laurels, araucarias, and other trees growing below a certain height were destroyed, but above that height they escaped; thus attesting, by unmistakable proof, to the great and rapid increase of the temperature with the height above the lower parts of the valleys.

165. *Distribution of Cold in Mountainous Countries during Winter.*—From the above remarks, it is evident that the distribution of temperature over the surface of a mountainous country during calm weather in winter, will be regulated by a different law than that of height above the sea. For the illustration of this point, it is fortunate that sixty-nine meteorological stations were established in Switzerland in 1863; and as one of the first-fruits of this Society, a paper has been lately published by Pro-

fessor E. Plantamour, on the Distribution of Temperature on the surface of Switzerland during the winter of 1863-64. Whenever the soil is colder than the air above it, the superficial layers become cold by contact, as already explained, and a system of descending air-currents set in over the whole face of the country. The direction and intensity of these descending currents are modified by the irregularities of the ground, and, like currents of water, they tend to converge and become united in the gorges and ravines, down which they flow like rivers in their beds. These currents give rise to counter-currents flowing over them to supply their place.

166. When the station is on the top of a mountain, as the Righi, the counter-current comes from a great height above the ground, and being therefore warmer, the temperature of such stations is comparatively high. At places situated on the sides of mountains, the influence of the counter-current tends to raise the temperature, though in a less degree than at the top, on account of the descending current from the heights above mixing with it. The Swiss villages being generally built on eminences rising out of the side of the mountains, and bounded on both sides by gorges and ravines, are admirably protected from the cold of winter. For the descending currents flow aside into the gorges, and the counter-currents are constantly supplying warmer air from the upper regions of the atmosphere.

167. Though the space occupied by the current of cold air in the bottom of a valley is of greater extent than the bed of a river, it is nevertheless limited, and on all occasions tolerably defined, so that on rising above it in ascending the slope, an increase of temperature is readily perceptible. The gradual narrowing or contracting of a valley has a very appreciable influence in lowering the temperature; for the valley is thus transformed into a basin almost closed, into which cold currents of air descend from all sides. On such occasions, a cold wind rushes impetuously down the narrow gorge, which serves as an outlet to the basin; and it is on this principle that many of the sudden gusts and breezes peculiar to mountain districts, such as *vent du Mont Blanc*, are to be explained. When the basin is a deep lake, the cold which is poured down on its surface, having cooled the surface water, is thereby conveyed to greater depths, and has therefore scarcely any effect in lowering the temperature of the air resting over the lake. Hence lakes are a source of heat during winter, and places situated at their outlet are not exposed to such gusts of cold wind as are referred to above.

168. *Influence of Forests.*—The temperature is found to be

warmer at the base of a mountain, and up its sides, when the slopes above are covered with trees. The beneficial influence of forests is exerted in two ways—viz., in the diminished radiation from the surface protected by the trees, and in the obstacle they oppose to the descending currents of cold air.

169. On the contrary, the cold of winter is more severely felt in those localities where the slopes above are destitute of vegetation, and consist only of bare soil and rocks, or of snow.

170. This peculiar distribution of the temperature only takes place during comparatively calm weather; during windy and stormy weather the law of the decrease of temperature with the height takes effect.

171. *Situations which afford the best protection against the Cold of Winter.*—In countries such as Great Britain, and, indeed, in most temperate countries, the majority of the deaths which occur are occasioned, or at least hastened, by low temperatures. In the tables of mortality and temperature, published weekly by the Registrars-General for England and Scotland, we have constant proof of this statement. For when, during the cold months of the year, the temperature happens to fall a few degrees, the death-rate at once rises to a height proportioned to the depression of the temperature. It is thus a matter of most vital importance, especially to invalids, to know the nature of those local situations which afford the best protection from low temperatures. From what has been already said regarding the increase of temperature with the height, it is evident that mere local situation may, during periods of great cold, have the effect of maintaining the temperature many degrees higher than what prevails at lower situations near at hand—a difference which will frequently assuage suffering, and on certain occasions save life. The advantage will of course be the greater if the sleeping-apartments be in the higher flats of the house. The dwellings most protected against severe cold, are those situated on a gentle acclivity, a little above the plain or valley from which it rises, having a southern exposure, and the ground behind planted with trees. It is chiefly on account of these natural advantages that Bridge of Allan owes its popularity as a winter resort for invalids. It may not be irrelevant here to draw attention more particularly to the degrees of advantage held out by different sites in the same town or village—the low-lying being the coldest, and those on slopes and sheltered by trees being the mildest.

CHAPTER V.

THE DISTRIBUTION OF TERRESTRIAL TEMPERATURE.

172. THE distribution of terrestrial temperature may be conveniently treated of under three heads—viz., the temperature of the sea, of the land, and of the air.

173. (1.) TEMPERATURE OF THE SEA.—The most striking fact regarding the temperature of the sea, as ascertained by soundings, is that below a certain depth, dependent on the latitude, an invariable temperature of about 39° prevails. The depth at which this temperature is met with at the equator is about 7200 feet. On receding from the equator it becomes less, until about latitude 56° it reaches the surface, unless where superficial currents push it into higher or lower latitudes. From 56° lat. towards the poles, this uniform temperature descends, and at 70° lat. it is 4500 feet below the surface.

174. Thus, then, the surface of the ocean is divided into three great regions—one surrounding each pole, where the temperature is below 39°, falling at the coldest parts to the freezing-point of sea-water; and the third the zone between these two, whose temperature is everywhere higher than 39°, rising at some places within the tropics to an annual mean of 85°.

175. How comes it that in the warmest parts of the globe, within the tropics, the temperature of the sea at all depths below 7200 feet is invariably as low as 39°, and that by far the larger portion of the water of the ocean remains constantly at this low temperature? In the first place, it must be kept in mind that the whole water of the seas over the globe is one body, and on account of its fluidity a free communication is kept up among its different parts. Again, since sea-water contracts, and consequently gains in density, as it is cooled until it freezes, the cold water will tend everywhere to flow towards and settle in the depths of the ocean. Thus it is evident that the sea will, below a certain depth, fall to one uniform temperature, and *that temperature just as cold as the*

surface temperatures of the sea over the whole globe can reduce it to. It is remarkable that 39° is the temperature at which pure water attains its maximum density. It may, however, be added, that this agreement is no more than a mere coincidence, there being no connection between the two facts.

176. *Surface Temperature of the Sea.*—This is one of the most important problems of meteorology and physical geography, but it has as yet been worked out only so far as to obtain no more than the very rudest approximation to a solution. The largest collection of facts bearing on the subject is in possession of the Board of Trade, consisting of 550,000 different observations. In addition to these it is estimated that upwards of a million are still required before sufficient materials are obtained for solving the problem of the temperature of the sea. It is expected that the British Government will immediately take steps to obtain the observations still desiderated, and to digest, tabulate, chart, and publish the results.

177. *Temperature of the Sea round Scotland.*—The part of the sea whose temperature is best known, is that portion surrounding the Scottish coast, of which, owing to the labours of the Scottish Meteorological Society, we have systematic observations during the last ten years. From these observations we learn that the mean annual temperature at the mouth of Loch Fyne is 49°.0, west of Oban 48°.7, Harris in Lewis 48°.9, Orkney 48°.8, Shetland 48°.4, and the mouth of the Firth of Forth 47°.8. Hence the Atlantic is 1°.0 warmer than the North Sea off the east coast of Scotland. The sea is also 1°.0 warmer than the air, and among the islands in the north it is 3°.0 warmer. But it is during winter that the difference between the temperature of the Atlantic and the North Sea is most apparent. The mean temperature of the Atlantic in July is 54°.4, and in January 44°.7; whilst the North Sea is 55°.5 in July, and 40°.8 in January. And if extreme temperatures be considered, the advantage in favour of the Atlantic is greatly increased, for the lowest temperature to which the Atlantic has yet been observed to fall is 39°.1, whereas at Trinity Pier in the Firth of Forth the temperature of the sea fell to 33°.7 in February 1865. These are the temperatures of deep water. In shallow water much lower temperatures occur. Thus Richard Adie has observed the temperature of the sea in the shallow estuary of the Mersey as low as 29°; and during the severe frost of Christmas 1860, the Moray Firth was frozen to a considerable depth a mile seaward.

178. *Temperature of the Sea in different parts of the Globe.*—Among the papers left in an unfinished state by Admiral Fitz

Roy, was one on the temperature of the sea. This paper has since been published, and is accompanied by a chart, on which the surface of the globe is divided into spaces ranging between 80° north latitude, and 70° south latitude, and bounded by each tenth meridan and tenth parallel. Those spaces, in themselves of unequal areas, and of different shapes, are named ten-degree squares, because of their uniformly rectangular appearance in the charts drawn on Mercator's projection. The mean temperature is printed on these ten-degree squares. Partly owing to the fewness of the observations made in many of the squares, and partly to the method adopted in reducing the observations, this chart of sea temperatures cannot be considered otherwise than as a rude approximation to the real temperatures of many of the squares. Thus, in the square including Great Britain, the mean temperature of the sea is stated to be 55°.8, which is, without a doubt, at least 3° or 4° too high; and in the adjoining square to the east, including the North Sea, the temperature of that sea is given as 50°.9, perhaps also a little too high. In spite, however, of this serious drawback, it is, and will be for some years to come, our best source of information regarding the temperature of the sea taken as a whole. On this ground we shall give some account of the temperatures as there laid down.

179. Owing to the small change of temperature within the tropics, the temperature of the sea in these parts is probably very near the truth. It is generally from 80° to 83°.5.

180. *Mean Temperatures of the different Oceans.*—Between the limits of 50° north and 50° south, the mean temperature of the North Atlantic is 71°.6, and that of the South Atlantic 66°.7. The South Atlantic is thus 5° colder, and this difference is nearly uniform for corresponding parallels of latitude. Similarly the mean temperature of the North Pacific is 69°.9, and that of the South Pacific 67°.7. Hence this ocean is colder south of the equator, but the difference is not so great as in the Atlantic. Of the three oceans south of the equator—the Atlantic, the Indian, and the Pacific—the Atlantic is the coldest, being 66°.7; the Indian is the warmest, 69°.3; and the Pacific is between the two, 67°.7. On the other hand, the North Atlantic is 1°.7 warmer than the North Pacific.

181. The mean temperature of the western half of the Mediterranean Sea is about 65°, and that of the eastern half, from 3° to 6° warmer; while that of the Black Sea is only 56°.8. On the other hand, the mean temperature of the Red Sea north of 20° lat. is 77°.4, but south of that parallel it is 81°.5. The great differences between the temperatures of these three seas cannot

but have an important bearing on the climate of the countries adjacent.

182. The highest temperature anywhere yet observed is 94° in the Red Sea, near Aden; the highest temperatures elsewhere are 91°, near Siam; and 89° and 88° in several places in the Indian Ocean near the equator.

183. *Abnormal Distribution of Temperature caused by Currents of the Sea.*—The following diagram gives the temperatures of the ten-degree squares as applicable to the North Atlantic:—

N. Lat. \ Long. West of Greenwich	80°–70°	70°–60°	60°–50°	50°–40°	40°–30°	30°–20°	20°–10°	10°–0°
70°–60°	—	—	38.2	36.7	49.0	49.1	49.4	52.0
60°–50°	—	—	45.6	44.1	52.7	55.8	56.8	55.8
50°–40°	—	51.6	54.7	56.3	61.5	60.1	59.7	57.8
40°–30°	64.1	64.6	68.2	70.6	68.4	67.2	66.7	65.3
30°–20°	77.7	77.5	77.8	73.3	74.8	72.5	71.0	—

From these figures it is evident that if a line be drawn from Cuba in the direction of the Faroe Isles, it will pass through higher temperatures than prevail to the eastward or westward of it. Now this anomalous temperature could not be maintained unless there was a general flow of the water of the ocean through the midst of the Atlantic north-eastward into the Arctic Ocean. This line of high temperature marks the course of the celebrated Gulf Stream, which, issuing from the Gulf of Mexico, spreads itself north-eastward over the Atlantic. By the warmth it brings from southern latitudes, the British climate is upwards of 20° warmer in winter than it would otherwise be. By the time it arrives at the British Islands, its passage is, no doubt, slow; but from the slow rate at which the temperature of the sea is brought

to a complete correspondence with that of the air, it will carry with it enough of its original heat to keep it warmer than the air, though it take some months to traverse the distance from the north of Ireland to Orkney. Observations prove that the temperature of the sea, as compared with that of the air, is about 3° higher in Orkney than it is in the south of Scotland.

184. Off the Gulf of Guayaquil in South America, the temperature of the sea is only 70°, being from 10° to 12° below the average of tropical seas. This extraordinary depression of temperature is brought about by the cold waters transported thither by the great *Humboldt Current* from the higher latitudes of the South Pacific. Proceeding westwards along the equator from Peru to the East India Islands, the temperature rises successively to 75°, 80°, 83°, and 84°.5. The last mean temperature, being the highest anywhere on the globe, occurs a little to the east of New Guinea. From this point to the east coast of Africa, including the whole of the northern half of the Indian Ocean, the temperature ranges from 81° to 84°; except near the mouths of some of the large rivers, where it is 1° or 2° less.

185. South of Sierra Leone, the temperature of the Atlantic is only 75°, but from this westwards it rapidly rises to 78°, 80°, 82°, and finally to 83°.5 in the confined waters of the Gulf of Mexico, in the Gulf of Honduras; but as the current traverses the gulf, and mixes with the colder water poured down by the Mississippi, the temperature falls to 76°.

186. The low temperatures on the east coast of North America are caused by a current from the frozen seas of the arctic regions flowing southward on the great bank of Newfoundland.

187. On the west coast of North America, the temperature of the sea increases from east to west. Thus proceeding from the shore westwards, the temperatures of the North Pacific by the ten-degree squares are respectively, between 20° and 30° N. lat., 63°.3, 66°.9, 74°.5, and 77°.7; between 30° and 40° lat., 56°.4, 61°.8, 64°.0, 71°.0; and between 40° and 50° lat., 49°.2, 53°.5, and 59°.0. Hence a cold current passes southward along the west coast of North America.

188. On the other hand, the temperature of the South Atlantic increases westward, showing a flow of the ocean southward along the east coast of South America, thus raising the whole temperature of that coast. The effect of the two opposite currents on the coasts of this continent, is to raise the temperature on the east coast from 8° to 10° above that on the west coast in the same latitude. The southern part of Africa is similarly situated with respect to currents, and the effect on the temperature of the sea is

even more marked than in the case of South America,—the temperature in the Gulf of Mozambique being 81°.1, while on the coast of Lower Guinea, in the same latitude, it is only 67°.6, the difference being thus 13°.5.

189. The sea on the east of Asia from China northwards becomes warmer as we recede eastward from the continent. Thus between 20° and 30° lat. the temperatures of the squares are 72°.4, 78°.8, and 83°.0; between 30° and 40° lat., 60°.0 and 66°.2; from which northwards in the Sea of Okotsk, it falls to 46°.7 and 34°.5 (?). Hence also the east coast of Asia is chilled by currents descending on it from higher latitudes. Cold currents also set in towards Australia from the south-west, depressing the temperature.

190. The lowest mean temperatures yet observed occur in the Antarctic Ocean, between 60° and 70° S. lat., immediately to the south of the Atlantic Ocean, and Australia and New Zealand. The lowest of these temperatures is 30°.9, occurring in 35° W. long. and 65° S. lat.

191. As regards their influence on climate, ocean-currents raise the temperature of the west of Europe, the east of South America, the east of Africa, and the south of Asia; and depress the temperature on the east and west coasts of North America, the west coast of South America, the west coast of Africa, the east coast of Asia, and the south coast of Australia.

192. It should be here remarked that the information gained from this chart, and from Maury's sailing directions regarding the currents of the sea, is in most cases of a very general character. The service already rendered to navigation by the knowledge thus disseminated has been of the most substantial kind; for by taking advantage of these currents, distant voyages are now accomplished sooner, and much time and money thereby saved. Much greater would be the advantage if our knowledge of the currents was fuller and more accurate than it is. When the scheme sketched out by the British Government will be completed, we shall be able to know, with sufficient accuracy for all practical purposes, the different currents of the ocean,—their temperature and density; their origin, course, and termination; the rate of their motion; the limits within which they are bounded; and the annual and secular changes to which they are subject.

193. In some cases the bed of the current is very distinctly marked off. The Gulf Stream, as it issues from the Straits of Florida, is a good example of this; and even after it has turned its course some distance to the eastward, it is in some places sharply defined. Thus when her Majesty's ship Nile was going from

Halifax to Bermuda in May 1861, Admiral Sir Alexander Milne found the temperature 70° at the bow, while it was only 40° at the stern, as he entered the Gulf Stream.

194. As an example of what may be expected from a thorough examination of the ocean, we may mention that on a cruise from Gravesend to the Faroes during August 1865, Dr George Keith, on the 7th, at 9 P.M., found the temperature of the sea, six miles off Whitby, to be 59°; on the following morning, twenty-five miles off Newcastle, it was only 52°; in the evening, when four miles off the Fern Islands, it was 54°; and on the morning of the 9th, five miles off St Abb's Head, it was 56°, at which point it remained till the latitude of the most northern point of Scotland was passed. Was the low temperature of the sea on the British coast from the Wash to Berwick, caused by a cold current from the Baltic Sea, issuing through the Skager Rack, and thence spreading itself westward toward the opposite coast of England? and if so, was it merely a temporary current, or a permanent current, or a current flowing only during certain seasons of the year? The effect of such a current on the climate of the north-east of England, especially when the wind is from the east, must be very great, but so meagre is our knowledge of the temperature of the North Sea, that no answer can be given to the above questions.

195. *Density of the Sea.*—The density of the sea, or the weight of a given quantity of sea-water, at a given temperature, is increased in proportion to the quantity of salt dissolved in it. It is always compared with the density of fresh water, which is considered as unity. The density is ascertained by means of the hydrometer, fig. 15, which is a glass vessel loaded with mercury or shot, and furnished with a scale. The zero point is found by floating it in pure water, at a temperature of 60°, and marking the point on the scale just where it meets the surface of the water.

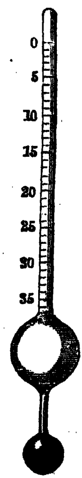


Fig. 15.

196. The South Atlantic is a little heavier than the North, the specific gravities being 1.02676 and 1.02664; but the difference between the South and the North Pacific is considerably greater, the South being 1.02658, and the North 1.02548. Hence of the two oceans north of the equator, the Atlantic is heavier than the Pacific; but this difference may be owing in part to the circumstance, that observations are wanting in the middle of the Pacific, where the density is probably greater than in other parts of that ocean. Of the three oceans south of the equator, the Atlantic is the heaviest, the Indian the lightest

and the Pacific intermediate between the two, the specific gravities being respectively 1.02676, 1.02630, and 1.02658.

197. In the case of land-locked seas, the density falls short of or exceeds the above average specific gravities of the sea, according as the evaporation from their surface falls short of or exceeds the amount of fresh water they receive from rain and the rivers which flow into them. Thus the density of the Mediterranean is in excess, and gradually increases from west to east; the mean of the western half is 1.0286, and of the eastern 1.0291. In the Red Sea the density is also great, and increases from south to north, being in the south 1.0272, and in the north 1.0297.

198. But in seas whose surfaces are small in comparison to the volumes of fresh water poured into them, the density falls far below the average. Thus the average density of the Black Sea is only 1.0143, the highest recorded is 1.0209, and the lowest, at a distance from the mouths of rivers, 1.0114. The average density of the western division of the Baltic Sea is 1.0112, and of the eastern only 1.0042. In the Baltic the highest yet recorded is 1.0232, and the lowest 1.0003, being nearly the density of fresh water.

199. Heavy rains diminish the density. The lowest specific gravity in the Indian Ocean occurs a little south of the equator, whereas in the Atlantic and Pacific Oceans it is to the north of the equator, in the belt of equatorial rains and calms. At the mouth of Loch Fyne, in Argyleshire, Dr Rankin observed the density of the sea to be 1.0210. This occurred on the 31st August 1860, after a heavy fall of rain, and at high water; next morning it increased to 1.0250, the usual density of the sea at that place. The effect of heavy tropical rains is often very striking. Thus Dr Ord of H.M.S. Hermes, on the 4th August 1859, at 9 A.M., observed the density to be 1.0266. Heavy rain fell, and in one hour the density was reduced to 1.0193; in two hours it rose to 1.0253, and in other three hours to 1.0266. In land-locked bays and arms of the sea, particularly if surrounded by hills, the very lowest densities are observed after heavy rains. In Hamnaway Loch, in the Hebrides, Captain Thomas has occasionally taken fresh water from the surface of the sea, the density being 1.0000.

200. Hence the chief differences in the specific gravity of the ocean arise from local circumstances. It is high where the evaporation is great, as in the region of the trade-winds, and low where much rain falls and in high latitudes in the neighbourhood of ice. It is highest in confined seas where there are few or no rivers and little rain falls; and lowest near the mouths of large rivers, and in seas like the Baltic, which are supplied with large quantities of fresh water.

201. *Currents caused by the different Specific Gravities of the Sea.*—If we except such partial currents as those caused by the tides and the winds, all the currents of the ocean are produced by the different density of the water of the sea at one place as compared with the water of the sea at another, whether it arises from different degrees of saltness or of temperature. Thus the seas of the two polar basins being about 50° colder than the sea within the tropics, their specific gravity is much greater. To restore the equilibrium, the warmer, and therefore lighter, water of the equatorial regions flows towards the poles, and the colder and denser water of the polar regions flows towards the equator. If the whole globe was covered with water of the same saltness throughout, the equatorial current would be seen everywhere flowing towards the poles as a surface-current, and the polar current could be detected by soundings flowing everywhere towards the equator as an under-current. But owing to the obstructions offered by the land, and by the inequalities of the bed of the ocean, and to the different degrees of saltness and therefore of density prevailing in different parts of the sea, these two great currents are broken up into the innumerable currents and counter-currents which diversify the face of the ocean and mark out the highways of commerce.

202. (2.) THE TEMPERATURE OF THE LAND.—In countries where the rainfall is pretty evenly distributed among the months, and where snow covers the ground but for a short period of the year, the mean temperature of the soil is almost identical with that of the air. But in countries where the year is divided into wet and dry seasons, and in countries where snow lies a considerable part of the year, the mean annual temperature of the soil may be a little above or a little below that of the air.

203. *Influence of Snow on the Mean Temperature of the Soil.*—The greatest difference between the temperature of the soil and that of the air occurs when the surface of the ground is covered for some months of the year with snow. Snow, from being a bad conductor of heat, prevents, on the one hand, the propagation of the cold of radiation downwards into the soil, and, on the other, the escape of heat from the soil into the air. Snow thus cools the air in two ways—(1) by retaining in the air almost the whole of the cold produced by radiation, and (2) by stopping up the supplies of heat which would otherwise be drawn from the soil. Since, for the same reasons, the temperature of the soil is kept warm, it follows that the temperature of the soil greatly exceeds that of the air when snow lies for some time on the ground. It is in Russia and Siberia that the greatest divergence between

these two temperatures is observed to take place. In Russia, about 120 miles south of Archangel, the mean temperature of the air is 32°, whereas that of the soil is 41°—the soil being thus 9° higher. In Semipolatinsk, in the south-west of Siberia, the temperature of the air is 41°, and of the soil 50°, or 9° higher than that of the air.

204. The daily changes of temperature do not affect the soil to greater depths than three feet. The exact depth varies with the daily range of temperature by which the amplitude or force of the daily heat-wave is determined, and with the nature of the soil. Similarly the heat of summer and the cold of winter give rise to a larger annual wave of heat propagated downwards, which becomes of less and less amplitude as it recedes from the surface, until it reaches a depth when it ceases to be perceptible. Principal Forbes has shown from the observations made on underground temperature on the Calton Hill, Edinburgh, that the annual variation does not penetrate further than 40 feet below the surface, and that below 25 feet it is very small. The depth at which the annual variation ceases to be observed, and where accordingly the temperature is constant, depends on the conductivity and specific heat of the soil or rocks, and particularly on the difference between the summer and the winter temperature.

205. Owing to the slow rate at which the annual heat-wave is propagated, the highest annual temperature of the trap rocks of the Calton Hill, Edinburgh, at the depth of 24 feet, takes place about the 4th January, and the greatest cold about the 13th July, thus reversing the seasons at that depth.

206. From the results arrived at by the observations of the Scottish Meteorological Society, made at depths of 3, 12, 18, 22, 36, and 48 inches below the surface, it has been found that there is a small but steady increase in the mean temperature at these various depths, from 3 inches downwards. To this conclusion there is no exception at any of the stations where such observations have been carried on. Further, Principal Forbes has shown from the Calton Hill observations, that the mean temperature increases from 3 feet downwards to 24 feet, the latter depth being fully a degree above the former. At 3 feet the mean temperature is 45°.83; at 6 feet, 46°.07; at 12 feet, 46°.36; and at 24 feet, 46°.88.

207. Springs which have their sources at greater depths than that to which the annual variation penetrates, have a constant temperature throughout the year. They may therefore be considered as giving a close approximation to the annual mean temperature of the locality, unless they come from a considerable

depth. All experiments made on Artesian wells and other deep borings, prove in the most conclusive manner that the temperature increases with the depth. It has been proved that in the chalk strata forming the lower part of the Paris basin, the temperature increases 1° for every 55 feet. In higher latitudes the increase with the depth is more rapid. Thus at Sakoutsh, in Siberia, the temperature at 50 feet is 15°.1 ; at 77 feet, 16°.5 ; at 120 feet, 21°.0 ; and at 382 feet, 30°.6—giving an increase of 1° in every 21 feet. The mean rate of increase over the globe is probably 1° of elevation of temperature for 50 English feet of descent.

208. Hence, then, the mean annual temperature increases from the surface as far down into the crust of the earth as man has yet been able to penetrate. It follows from this important result that heat must be constantly passing from the interior of the earth to its surface, whence it escapes into space; *and hence the temperature of the whole earth must be cooling from year to year.* Sir William Thomson of Glasgow has calculated that during the last 96,000,000 years the rate of increase of temperature under ground has diminished from 1° for every 10 feet, to 1° for every 50 feet, of descent as at present; and adds that, if this action had been going on with any approach to uniformity for 20,000 million years, the amount of heat lost out of the earth would be more than enough to melt a mass of surface-rock equal in bulk to the whole earth; and in 200 million years it would be enough to melt the rocks forming the earth's crust. If this reasoning be just, geologists cannot claim a much higher antiquity for life on the globe than 100,000,000 of years.

209. (3.) Distribution of Temperature in the Atmosphere. —The distribution of heat over the globe is best represented by isothermal lines, or lines drawn through all places having the same mean temperature. The mean annual temperature is shown by the isothermals in Plate I.; the warmest month, in the northern hemisphere, July, in Plate II.; and the coldest month, January, in Plate III. The part of the earth's surface which has the highest mean annual temperature, forms an irregularly shaped belt lying along the equator, and comprised between the north and the south isothermals of 80°. On either side of this warm belt the temperature diminishes towards the poles; and the lines showing successively this diminution are, speaking in a loose sense, arranged parallel to the equator, thus showing the all-predominating influence of the sun as the source of terrestrial heat. The coldest portion of the globe is a small oval-shaped patch, near to, but not surrounding, the north pole, its mean annual temperature being −4°. Its

narrowest diameter lies north and south; it nearly touches the pole at the northern extremity, and extends as far south as 72°.30 N. lat., in 130° W. long. Part of it appears in the diagram. On examining the isothermal of 0° or zero, one might be led to suppose that there are two separate centres of greatest cold, one north of Siberia, and the other north of British America. Such, however, is not the case. What appears to be two distinct centres is solely due to the isothermals being drawn on Mercator's projection of the earth. If the line be drawn on a polar projection, the isothermal of 0° encloses one connected space of greatest cold, and not two such spaces, as is not unfrequently stated in books.

210. While the decrease of temperature in advancing toward the poles corresponds in a general way to what may be called the solar climate, there are deviations brought about by disturbing causes too important to be overlooked. These disturbing causes are—(1) the currents of the sea, (2) the prevailing winds, and (3) large surfaces of water which are frozen over during part of the year.

211. *Effect of the Currents of the Sea on Climate.*—The influence of an oceanic current on climate depends on the temperature of the place it leaves, and that of the place toward which it flows. Hence the great equatorial current flowing from east to west does not require to be considered here, because the heat remains the same throughout its course. It is those currents which convey the waters of the sea to high or to lower latitudes that require to be considered.

212. *Gulf Stream.*—Of these, the most important as well as the most marked is the Gulf Stream, which, by conveying the warm waters of the south to the arctic regions, pushes the isothermals many degrees northward. The effect on the climate of western Europe during the year, and especially during winter, Plate III., receives striking illustration from the charts. If no more heat was received than is due to the position on the globe in respect of latitude, the mean winter temperature of Shetland would be only 3°, and that of London 17°. But owing to the heat given out by the Gulf Stream during winter, and carried to these places by the winds, their winter temperatures are respectively 39° and 37°—Shetland being thus benefited 36°, and London 20°, from their proximity to the warm waters of the Atlantic. In Iceland and the Norwegian coast, the increase thus accruing to the winter temperature is very much greater. To these places the Atlantic may be conceived as a vast repository of heat, in which the warmth of the summer months, and the warmth of more southern regions, is treasured up and reserved against the rigours of winter.

213. *Winter Temperature of the British Islands.*—The Gulf Stream leaves its impress unmistakably on the temperature of each of the months, as shown by the position of the monthly isothermals. In winter, fig. 16, the deviation from their normal,

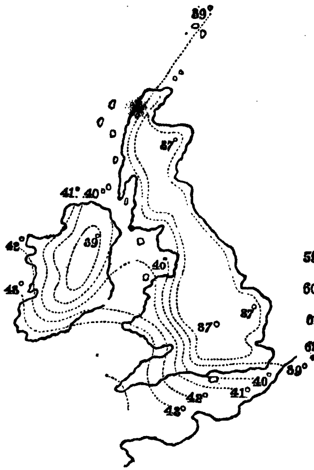


Fig. 16.

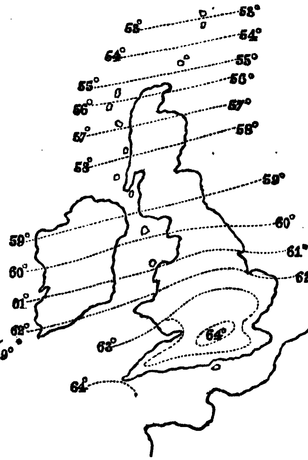


Fig. 17.

or east and west direction, is greatest. Indeed, as regards Great Britain, the lines are then at right angles to this normal direction, and lie north and south. In Ireland they seem to envelop the island with their folds, which increase in warmth from the centre of the island outward to the ocean. This points out clearly that the great source of heat from which the climate of Great Britain derives its warmth in winter is in the west; in other words, it is regulated by the ocean.

214. This peculiar distribution of the winter temperature of the British Islands has important bearings on the treatment of diseases. Since the temperature of the whole of the eastern slope of Great Britain is the same, it is evident that to those for whom a milder winter climate is required, a journey southward is followed by no practical advantage, unless directed to the west coast. And as the temperature on the west is uniform from Shetland to Wales, Scotland is as favourable to weak constitutions during winter as any part of England, except the south-west. The temperature on the south-west of England and Ireland being, however, 4° higher than the west of Scotland, the mildest climates,

and therefore the most suitable resorts for invalids, are to be found from the Isle of Wight westward, round the Cornish peninsula to the Bristol Channel, and from Carnsore Point in Ireland to Galway Bay.

215. A similar though much feebler current passes from the North Pacific, through or towards Behring Strait, and there accordingly the isothermals are pushed a little to the northward. Part of this current returns by the west coast of America, depressing the temperature, especially the summer temperature of these parts, Plate II. The two great currents in the southern hemisphere flowing northward from colder to warmer latitudes—viz., Humboldt's, from the Antarctic Ocean to Lima by the coast of Peru, the other from the Cape of Good Hope along the west of Africa—lower the temperature, and thus drive the isothermals nearer the equator. Again, the great equatorial current, after impinging on the east coast of Africa, turns southward, and by the warmth it imparts pushes the isothermals into higher latitudes along the east of Africa. And for the same reason the current flowing past the Brazil coast southward, raises the temperature in the east of that country.

216. In all cases the influence of these currents is most distinctly marked in January and July, the months of extreme temperatures. Thus the warm current of the Gulf Stream is most felt in January, when several of the *isochimenals*, or lines of mean winter temperature, are carried by it 1600 miles northwards of their normal position. Similarly the currents from the Antarctic Ocean being coldest in July, the isothermals are most deflected from their normal position during that month, the distance being about 1300 miles nearer the equator. About the most remarkable lowering of the isothermals occurs on the Labrador and Newfoundland coasts during May and June, being caused by the icebergs which then descend on these coasts through Davis Strait.

217. *Effect of Winds.*—Since winds bring with them the temperature of the regions they have traversed, the equatorial current is a warm wind, and the polar current a cold wind. Also, since the temperature of the ocean is more uniform than that of the land, winds coming from the ocean do not cause such variations of temperature during the year as winds from a continent. As an atmosphere loaded with vapour obstructs both solar and terrestrial radiation, it is plain that moist winds blowing from the ocean are accompanied with a mild temperature in winter, and a cool temperature in summer; and dry winds coming from continents with cold winters and hot summers. Again, the equatorial current, losing heat as it proceeds in its course, is thereby brought

nearer the point of saturation, and consequently becomes a moister wind; whereas the polar current, gaining heat in its progress towards the equator, becomes a drier wind. Hence the S.W. wind in Britain is a particularly moist wind, because it is both an oceanic and equatorial current; whereas the N.E. wind, on the contrary, is peculiarly dry and parching, because it is both a polar and continental current.

218. The height and direction of mountain-ranges is an important element to be taken into account in estimating the influence of winds on climate. If the mountain-chains lie perpendicular to the course of the wind, and at the same time are of great height, the effect will be to partially divert the winds from their course. Thus the N.E. trade-wind, after crossing the Gulf of Mexico, is turned aside from its course by the lofty range of the Rocky Mountains, and ascends the basin of the Mississippi. But the chief effect mountain-ranges have on the temperature is to drain the winds which cross them of their moisture, and thus to cause cold winters and hot summers in places to the leeward, as compared with places to the windward, by more fully exposing them to both solar and terrestrial radiation. Of this, Norway and Sweden afford, perhaps, the best illustration. For whilst the difference between the summer and winter temperatures of Hernösand, on the Gulf of Bothnia, is 42°.3, the difference between those of Söndmör in the same latitude, but on the other side of the Dovréfeld Mountains on the coast, is only 33°.8. In the British Islands, the same differences between the east and west are considerable; thus, on the coast of Essex, the difference is 26°, whilst in Kerry it is only 18°. A large part of this difference is due to the great dryness of the air in the east as compared with the west.

219. These considerations explain the position of the isothermals in the north temperate zone, where the prevailing wind is the S.W. or anti-trade. In January, Plate III., the western parts of each continent enjoy a comparatively high temperature on account of their proximity to the ocean, whose high temperature the winds waft thither; and further they are protected from extreme cold by their moist atmosphere and clouded skies. But in the interior of the continents it is otherwise. For the winds getting colder and drier as they advance, the soil is exposed to the full effects of radiation during the long winter nights; and since the ground is for the most part covered with snow, little heat can ascend from the soil to counteract the cold on the surface; and as a consequence the temperature rapidly falls. In the interior of Siberia, the January temperature falls to $-40°$, which is 9° colder

than the coldest part of the American continent. This is the greatest mean monthly cold known to occur on the surface of the earth, allowance being made for height above the sea.

220. On the other hand, the interior of continents is much hotter in summer than their western parts, because the land being warmer than the sea at this season, the wind increases in temperature as it passes over it. Since the air is also drier, the heating power of the sun's rays is very great during the long days of summer.

221. Hence the countries in the interior and in the east of Asia and America are characterised by extreme climates, and the countries in the west by equable climates. Thus at Yakutsk, in Siberia, the temperature in July is 62°.2, and in January $-43°.8$; whereas at Dublin these are respectively 60°.8 and 38°.5. Thus the difference between the summer and winter temperature at Yakutsk is 106°.0, whilst at Dublin it is only 22°.3. The temperature of New Archangel, in Sitcha, in the west of North America, is 55°.6 in July, and 32°.4 in January; whereas at Fort York, on Hudson Bay, in the same latitude, the July temperature is 60°.0, and the January $-5°.1$, thus giving a difference of only 23°.2 between the summer and winter temperature on the coast of the Pacific, but of 65°.1 in the interior of the continent.

222. Fig. 17, showing the *July temperature of the British Islands,* shows that the law takes effect also over comparatively narrow tracts of land. The temperature of the east and the interior exceeds that of the west; and Ireland may be observed to widen the distance between the isothermals—that is, to increase the summer temperature in the parts of Great Britain lying to the east of it. Great Britain owes more to Ireland than is generally supposed.

223. It is this which makes the most important distinction among climates, both as respects animal and vegetable life. On man especially the effect is very great. The severity of the strain of extreme climates on his system is shown in a striking manner by the rapidly increasing death-rate according as the difference between the July and the January temperatures is increased. Thus the mortality is 8 per cent greater in England than in Scotland, the climate of the latter country being more equable or insular in its charcter; and it is found on advancing into the continent of Europe, that the more extreme the climate becomes, so much the more is the death-rate increased.

224. *Influence of large surfaces of water frozen during part of the year.*—The great fresh-water lakes of North America—Lakes Superior, Huron, Erie, Michigan, Ontario, Bear Lake, &c.—exercise

an important influence on the climate of the interior of America. For in winter, America, with its frozen lakes, is a truly unbroken continental mass, and its winter climate is therefore continental; whereas in summer its numerous large sheets of fresh water communicate to those parts many of the characteristic features of an insular summer climate. At Fort Brady, which is situated in the district where Lakes Superior, Michigan, and Erie nearly approach each other, the temperature of July is 64°.6; but at Fort Snelling, to the west, in Minnesota, and nearly in the same latitude, it is 73°.4, the difference being chiefly caused by the cooling effects of the inland seas which surround Fort Brady. On the other hand, the temperature of these two places in January and February are the same.

225. The combined effect of the disturbing causes is seen at once if we compare the observed temperature with the *normal temperature*, that is, the temperature due to a locality in respect of its latitude alone. Dove has published an elaborate set of maps, constructed on this principle, in which he shows by a system of *Thermic Isabnormals* the deviations from the mean of each month, and of the year, in the different parts of the globe. Those maps show that in January, in the northern hemisphere, the sea and the western parts of the continents are in excess of their normal temperature, but elsewhere a deficiency. There are two centres of excess—one to the north-east of Iceland, amounting to 41° of excess; the other in Russian America, amounting only to 18°. On the other hand, there are two centres where the temperature is deficient—one at Irkutsk, amounting to 41°; and the other west of Hudson Bay, amounting to 27°. In July, the United States of America, Europe, Asia, the Indian Ocean, the north of Africa, and the extreme north of South America, have their temperature in excess, while elsewhere it is deficient. The centres of greatest excess are the north of Siberia, 13°.5 of excess; the Red Sea, 11°; and the north-west of the United States, 4°.5. The centres of greatest defect of temperature are the entrance to Hudson Bay and the Aleutian Islands, the defect in each case being 11°.

226. While the temperature of each place on the earth's surface is undergoing more or less change from day to day, rising in summer and falling in winter, it might be supposed that the temperature of the earth itself, considered as a whole, would remain constant, from day to day, throughout the year, since the quantity of solar heat poured into it is the same from day to day. Such, however, is not the case; for from July to December, when the sun is south of the equator, a large amount of solar heat

passes into the latent state owing to the extensive evaporation from southern oceans, and is conveyed by the winds into the northern hemisphere. But from January to June, when the sun is north of the equator, the evaporation being much less, owing to the larger proportion of land in the northern hemisphere, less heat is lost in this way. From this it follows that the earth itself has an annual march of temperature, reaching the maximum at the time of midsummer, and the minimum in the middle of winter, in the northern hemisphere. Sufficient materials have not yet been collected for determining with accuracy the annual range of the earth's temperature. Professor Dove has, however, attempted an approximate solution of the problem, of which the following is the result:—

	N. Hemisphere.	S. Hemisphere.	Whole Earth.
Temperature for July,	70°.9	53°.6	62°.3
Ditto for January,	48°.9	59°.5	54°.2

From this investigation the temperature of the whole earth, as shown by the thermometer, would appear to be 8°.0 warmer in July than it is in January.

227. *Decrease of Mean Temperature with the Height.*—The decrease of temperature with the height is perceptibly felt on ascending mountains, and is still more evident in the snow-clad summits which may be seen even in the tropics. For this decrease several reasons may be assigned. In rising from the surface of the earth, we recede from a warm body and approach nearer the cold regions of space. Since little of the sun's heat is absorbed in passing through the atmosphere, but almost the whole goes to warm the surface of the earth, it is evident that the lower strata of the air, in contact with the earth, will be most heated by the sun's rays, and the upper strata least. But suppose that the same amount of absolute heat (latent and sensible combined) was in the atmosphere at all heights; then since the air in the higher regions of the atmosphere is subjected to less pressure, it occupies a greater space, or the particles are further apart. Now to keep the aërial particles further asunder, more heat will be required to pass into the latent state, and hence the temperature of the higher regions of the atmosphere will be colder. Again, since at elevated situations the atmosphere of invisible vapour intervening between them and space is much less than at lower levels, such situations are less protected from the chilling effects of terrestrial radiation. This supposition is confirmed by the circumstance that the low mean temperature of high places is chiefly caused by the low temperature during the nights, and during the

winter season when terrestrial radiation is the main influence at work modifying the temperature. On the other hand, during calm summer weather, when solar radiation is greatest, the temperature generally rises as high in many situations 1000 feet high as it does at places adjacent, but near the level of the sea.

228. From what has been here advanced, it is plain that the rate at which the mean temperature falls with the height, is a very variable quantity—varying with the latitude, the situation, the dampness or dryness of the air, calm or windy weather, and conspicuously with the season of the year. Accordingly, much diversity of opinion exists regarding the rate of decrease to be allowed in reducing temperature observations to sea-level. For the five years ending with December 1861, the mean annual temperature of Montrose, Forfarshire, 14 feet above the sea, was 47°.2, and of Braemar, Aberdeenshire, 1110 feet high, 43°.5. This gives the rate of decrease, 1° to every 296 feet, or nearly 1° for every 300 feet, the rate of decrease most generally adopted.

CHAPTER VI.

THE MOISTURE OF THE ATMOSPHERE.

229. *The Two Atmospheres of Air and Vapour.*—The gaseous envelope surrounding the earth may be considered as composed of two distinct atmospheres—an atmosphere of dry air and an atmosphere of vapour. The dry air, oxygen and hydrogen, is always a gas, and its quantity is constant from year to year; but the vapour of water does not always remain in the gaseous state, and the quantity present in the atmosphere is, by the processes of evaporation and condensation, varying every instant.

230. According to the strength of the force of cohesion drawing the particles of matter together, as compared with the repulsive energy of heat driving them asunder, so is the body solid, liquid, or gaseous. In solids and liquids the cohesive force is in excess, whilst in gases it is absent. It is the absence of cohesion which is the distinctive characteristic of gases and vapours. If a little water be poured into a vessel it will only rise to a certain level, and leave the rest of the vessel unoccupied. On the contrary, gases and vapours completely fill the vessel in which they are; thus, instead of cohesion, there is a mutual repulsion among their particles. Since, then, the particles constantly tend to recede from each other, it follows that they will exert an outward pressure on the sides of the vessel, and that the amount of this pressure will be proportioned to the repulsive force, or to the elasticity of the gas.

231. From the circumstance that a gas fills completely the vessel which contains it, it will be seen that its volume is determined by the pressure to which it is subjected. The law of the compression of gases was discovered by Boyle and Marriotte. It is generally known as Marriotte's law, and is as follows:—At the same temperature, the volume occupied by the same gaseous mass is in inverse ratio to the pressure which it supports: consequently the density and tension of a gas are proportioned to the pressure—

that is, air under a pressure equal to that of two atmospheres will only occupy half the bulk it occupied when under the pressure of one atmosphere; under the pressure of three atmospheres, one-third of that bulk, &c. At the pressure of 770 atmospheres, air would become as dense as water. But by doubling the pressure we double the elasticity.

232. This law is true for air at all pressures and temperatures which have hitherto been tried; but it does not hold good for the vapour of water, neither as respects pressure nor temperature. Under low pressures the vapour of water follows the law; but under high pressures the space occupied is less than would have been if the law had been observed, because part of the vapour then passes into the liquid state, thus occupying less space.

233. Since it is the repulsive force of heat which drives the particles of bodies asunder, it is evident that an increase of temperature will add to the elasticity of gases, and a decrease of temperature diminish it. Conversely, if part of the pressure exerted in a given quantity of gas be removed, the gas will increase in bulk and fall in temperature; but if the pressure be increased, the volume of gas will be less, and its temperature higher. Since the pressure is diminished as air ascends and increased as it descends in the atmosphere, it follows that as currents of air ascend they become colder, and as they descend they become warmer. This law applies to air at all temperatures, but is not applicable to the vapour of water.

234. There is another property of gases and vapours by which they are distinguished from liquids. If mercury, water, and oil be poured into a vessel, they will settle according to their densities, mercury on the bottom, oil on the top, and water between the two; and they will remain in these relative positions without exhibiting any tendency to mix together. But if gases of different densities be put into the same vessel, they will not arrange themselves according to their densities, but will ultimately be diffused through each other in the most intimate manner. Each gas tends to diffuse itself as in a vacuum. The effect of the presence of other gases is only to diminish the rate of expansion and thus retard their mutual diffusion. This equal intermixture occurs with all gases and vapours which do not act chemically on each other, and when once such a mixture is effected it remains permanent and uniform. Of this, common air, which is a mixture of oxygen and nitrogen, is an example. As regards the atmosphere, the result of this law is, that vapour diffuses itself through the dry air, the presence of the air having only the effect of retarding the rate of its diffusion.

235. If the vapour of water remained permanently in the atmosphere—that is, was not liable to be withdrawn from it by being condensed into rain—the mixture would be as complete and uniform as that of the oxygen with the nitrogen. But the equilibrium of the vapour atmosphere is being constantly disturbed by every instance of condensation, by the ceaseless process of evaporation, and by every change of temperature. From these considerations, and from the circumstance that the dry air greatly obstructs the free diffusion of the vapour, it follows that the law of the independent pressure of the vapour and of the dry air of the atmosphere does not absolutely hold good, but that from the constant effort of the vapour to attain to a state of equilibrium there is a continual tendency to approach to it. And since the independent and equal diffusion of the dry air and the vapour is, owing to disturbing causes, never reached, it follows that the observations of the hygrometer only indicate local humidity, and should only be regarded as approximations to a correct indication of the quantity of vapour in the atmosphere over the place of observation. It should, however, be added, that though in exceptional cases the amount of vapour indicated may be wide from the mark, yet in long averages a very close approximation will be obtained.

236. Vapour is continually passing into the air from the surface of water and moist surfaces at all temperatures by the silent process of *evaporation*. Evaporation also takes place from the surface of snow and ice. In evaporation the vapour is supplied only from the surface of the water; hence the extent of surface in contact with the air greatly influences the amount and rate of evaporation. By the increase of temperature the elastic force of the vapour in the atmosphere is increased, and with it the rate of evaporation. The atmosphere can contain only a certain amount of vapour, according to the temperature; hence, when it already has in suspension its full complement, or when it is saturated with moisture, evaporation ceases. Conversely, evaporation would be greatest when the air is perfectly dry or free from vapour. Since currents of air remove the saturated air and substitute dried air to the evaporating surface, evaporation is much more rapid in windy than in calm weather. Though the quantity of vapour required to saturate a given space is the same, whether that space is occupied with air or in a vacuum, yet the time occupied in completing the saturation increases with the pressure on the surface of the fluid. When water evaporates into a vacuum, the maximum density of the vapour is acquired at once; but when it evaporates into air it is not acquired till some time has elapsed. And since every addition to the vapour increases the pressure, the

rapidity of the evaporation is under these circumstances continually diminishing.

237. *Evapometer.*—The instrument for measuring the quantity of water which the atmosphere can take up from the surface of water in the form of vapour in a given time is called an *evapometer.* In its simplest form it consists of an evaporating dish, about 5 inches in diameter, with an overflow pipe a little below the surface fitting into a bottle, and furnished with a wire-work cover. The amount of evaporation is ascertained by filling the dish to the point of overflowing, which is, let us suppose, 3 inches of water. An ordinary rain-gauge goes along with it for the purpose of ascertaining the amount of rain which may fall. In making an observation the water remaining in the dish is measured, together with any that may be in the receiving bottle, and also the depth of rain fallen. Add the rainfall to the 3 inches, then add the water remaining in the dish to that contained in the bottle; and the difference of the two sums is the amount evaporated. The best evapometer is one invented by Dr Arthur Mitchell. It consists of an evaporating dish, the losses in which are supplied as they occur from a reservoir whose area is ten times, or any number of times, less than that of the evaporating dish, the principle being the same as that involved in the fountain inkstand, or the fountain drinking-cup of the bird's cage. The water in the dish is thus always kept at the same level, and any rain that falls is at once carried off by an overflow pipe so constructed as to prevent any error arising from the waves raised by the wind on the surface of the evaporating dish. The advantages of this instrument consist in the rain and dew being at once conveyed away, and the facility with which minute quantities can be read off. As the reservoir is liable to be broken in the time of frost, a modification of this evapometer has been devised by Mr James Procter, Barry, one of the ablest observers of the Scottish Meteorological Society. His evapometer presents a surface of 10 inches square, with an overflow pipe at the level of the zero line. The small quantity daily evaporated is measured by a scale of brass divided into 10 equal parts placed diagonally in the evaporation-vessel, so that during the evaporation of one inch of water, *the line of contact of the surface of the water with the diagonal scale will traverse the whole length of the scale.* Since each of the 10 parts may be subdivided by the eye into 10 parts, the 100th part of an inch may be easily read on the scale.

238. There is another evapometer, or *Atmometer*, fig. 18, which from its simple construction will be found to possess some practical value. It consists of a long glass tube graduated into inches,

having attached to the bottom a hollow ball of porous earthenware similar to that used in water-bottles. In using it, water is poured in at the top till it rises to the zero point of the scale. The outside of the porous ball being always covered with dew, the more rapid the evaporation, the more quickly will the water fall in the tube.

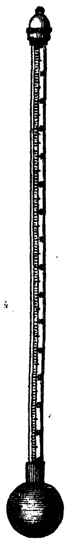


Fig. 18.

239. There is no class of observations which show such diversity, we may almost say contrariety, of results, as those made by different observers on evaporation. This arises from the different methods employed. The object sought to be obtained is the *drying power* of the atmosphere, a question of prime importance in its relations to the animal and vegetable kingdoms. And since none of the ordinary meteorological observations enable us to arrive at this element with any approach to exactness, it is hoped that some one evapometer, such as Dr Mitchell's, will come to be generally used among observers.

240. *Loss of Heat by Evaporation.*—One of the most important consequences of evaporation is the loss of heat which accompanies it. During the conversion of a liquid into the gaseous form, a very large quantity of heat disappears; and since it becomes imperceptible to the senses or to the thermometer as long as the gaseous state is retained, the heat is said to become *latent*. It must be kept in mind that the heat which thus appears to be lost, is not destroyed, but may be recovered or made evident at pleasure by bringing back the vapour to its original liquid state. In the gaseous state the force of the heat is expended in keeping the particles of vapour further apart than they were in the liquid state, and hence the thermometer is not affected by it. The change of water to vapour by evaporation being thus productive of cold, and the conversion of vapour to water productive of heat, one or two important consequences follow. The ocean loses more heat from evaporation than the land, because the quantity evaporated from its surface is much greater. Again, since more rain falls on land than on sea, especially in hilly and mountainous countries, the temperature of the air over the land will be still further raised by the latent heat thus given out. For this reason the northern hemisphere is warmer than the southern (art. 226).

241. *Effect of Drainage on the Temperature of the Soil.*—Theory should lead us to suppose that the temperature of drained land would be higher than that of undrained land, because, being drier, less heat is lost by evaporation. In order to bring this supposition to the test of experiment, the Marquess of Tweeddale in

1862 offered prizes to the amount of £80 for sets of observations on the temperature of drained and undrained land on mountain pastures, and on arable land under crops of turnips, wheat, and ryegrass. Two sets of observations, each extending over a year, were made, one at Otter House in Argyle, on arable land under a ryegrass crop, the soil being light and sandy and sloping 1 in 40 feet, and the other set at North Esk Reservoir, Pentland Hills, on hill pasture, the soil being clay mixed with decayed moss. From these valuable observations the following results were drawn:— 1. The mean annual temperature of the arable land was raised nearly a degree (0°.8) by drainage. 2. The temperature of the hill pasture was also raised by drainage, but not to the same extent (0°.4). 3. During sudden falls of temperature and during protracted cold weather, as when the soil was under a covering of snow, the cold passed more quickly and completely through undrained than through drained land. 4. When the temperature of the air was higher than that of the soil, drained land received more benefit from the higher temperature than undrained land, less of its heat being lost by evaporation. 5. Since, when rain or sleet fell, the superfluous moisture soon flowed away from the drained land, it being sandy and the slope considerable, drainage tended to maintain in the soil a comparatively equable temperature; whereas the undrained land was liable to considerable fluctuation, for when soaked with warm rain-water its temperature was temporarily raised, and when soaked with melted snow it was temporarily lowered. On one occasion sleet showers lowered the drained land 2° and the undrained land 4°. 6. The temperature of drained land was in summer occasionally raised above undrained land 3°, often 2°, and still more frequently 1°.5; and hence the beneficial effects of drainage are sometimes as great as if the land had been transported 100 or 150 miles southwards.

242. Since these different temperatures are chiefly caused by the different amounts of water evaporated from the land, it is evident that different results will be obtained from different soils, with different crops, and with different slopes and exposures.

243. In 1847 Professor James Elliot made a number of experiments which throw some light on this extensive subject. He found that peat-moss can absorb more than twice its own weight of water, dry clay nearly its own weight, dry earth or garden mould more than half its own weight, and dry sand little more than a third of its own weight. With equal times of drying under the same circumstances, peat-moss lost $\frac{2}{3}$ of all the water it contained, clay and earth each more than $\frac{3}{4}$, and sand more than $\frac{9}{10}$. Evaporation was greater from the surface of loose earth than from

the surface of water, till the earth was so far dry as to be of a light colour. Evaporation from saturated moss was excessive during the first day, being far more than from the surface of water; but on the second day the water began to evaporate most, and on the third day very much more, although the moss was still wet 10 inches below the surface.

244. Two years ago Mr D. Milne Home of Wedderburn made the following experiment: Two boxes of the same size were taken and filled, one with sandy loam, and the other with strong clay. Each was suspended at the end of a balance, and so adjusted that the one box was exactly equal in weight to the other. An equal quantity of water was poured into each box. Before a week had elapsed, the box with the sandy loam rose above the level of the other box, more water having evaporated from it than from the strong clay, and during that time the temperature of the sandy loam was almost always lower than that of the clay.

245. From these experiments a few practical conclusions may be drawn. In all cases the amount evaporated from wet substances, and the consequent decrease of temperature, are proportioned to the number of evaporating points, or to the whole extent of the evaporating surfaces in contact with the air. This explains why evaporation is greater from wet moss and grass than from wet soils, and greater from wet soils than from the surface of water. But as evaporation proceeds and the substances begin to dry, the rate of evaporation is modified by the facility with which the water is drawn by capillary attraction from the interior of the substances to their evaporating surfaces. Thus dry sand parts with its moisture sooner than common mould, common mould sooner than clay, and clay sooner than peat-moss. In respect of evaporation, drainage affects the temperature of the soil in two ways: (1) By keeping the soil drier, and thus diminishing the evaporation, it raises the temperature. (2) Since a dry soil is more friable than a wet soil, and thus presents more evaporating points, it is probable that on soils bare or nearly bare of vegetation, and therefore freely exposed to the influence of the weather, the effect of drainage will be to lower the temperature for some time after rain, or as long as the evaporation exceeds that of undrained land. It is evident when the soil is covered with vegetation that this peculiarity can only obtain in a very limited degree.

246. *The Hygrometry of the Atmosphere.*—At all temperatures, even the lowest, moisture exists in the atmosphere in an invisible state, so that the air is never absolutely dry. Intervals occur between the particles of air which are partially filled with the vapour that is constantly rising from the earth. This property is termed

the capacity of the air for moisture, and when the intervals between the particles are full of vapour, the air is said to be saturated. Professor J. D. Everett constructed a hygrometer (Dry-and-Wet-bulb) with the degrees on a large scale and carefully compared with a standard, and found that the exact correspondence of the two thermometers, which happens when the air is perfectly saturated, is an event of as rare occurrence as eclipses of the sun or moon. Thus, then, though every time dew is formed the air in contact with the ground must be brought to the point of saturation, and every time cloud is formed and rain falls the point of saturation is also reached where the condensation takes place, yet the air a few feet above the ground is seldom perfectly saturated.

247. An increase of temperature, by expanding the air and thus separating the particles farther from each other, increases the capacity of the air for moisture. On the other hand a fall of temperature, by drawing the particles closer together, diminishes the capacity. But the capacity of the air for moisture increases at a more rapid rate than the temperature. Thus, air can contain at 32° the 160th part of its own weight; at 59° the 80th part; and at 86° the 40th part; the law being that for every increase of 27° the capacity is doubled.

248. *Hygrometer.*—The instrument for ascertaining the amount of vapour in the atmosphere is called a *hygrometer*. There is a great variety of hygrometers, differing both in form and in principle of construction. Some are formed of substances which, by readily absorbing moisture from the air, and as readily parting with it, change in form and size, and thus give some indication of the amount of vapour present in the air. Of these the most noteworthy is the hair hygrometer of Saussure, which, when the air is damp, absorbs moisture and becomes shorter, and, when the air is dry, returns to its original length. The *conservatory hygrometer* (fig. 19), constructed by Richard Adie, belongs to this class. The pointer is made of two pieces of wood glued together, so that increasing dampness twists it to the right, and increasing dryness to the left. Though of little or no scientific

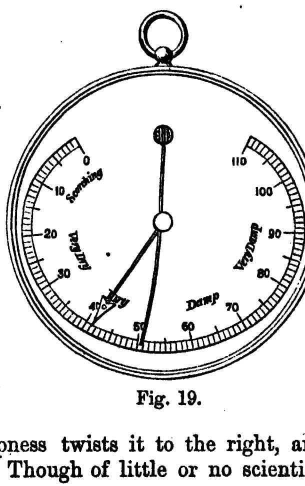


Fig. 19.

value, yet it may be turned to good account in the sick-room or in conservatories.

249. It is this property of substances to be changed in bulk in attracting moisture from the atmosphere, or in parting with it, which explains a large number of popular prognostics of the weather, especially such as refer to the feelings and conduct of animals, the opening and closing of flowers, and the lengthening and shortening of strings, cordage, and other materials.

250. Hygrometers constructed on the principle of absorption are faulty, not only because they are irregular in their action, but also because in the course of time they are subject to great change. The most accurate hygrometers are those constructed on the principles of condensation or of evaporation. A familiar illustration of the principle of condensation is the forming of dew on a tumbler filled with cold water on being brought into a warm room. This dew is caused by the deposition of moisture from the air, which, in contact with the cold surface of the glass, is now cooled down below the point of saturation. The temperature of the glass at the moment dew begins to form on its surface is termed the *dew-point*, which corresponds with the point of saturation.

251. Daniell's and Regnault's hygrometers are constructed on the principle of this simple phenomenon, having only superadded to them various contrivances for reducing the temperature quickly to any point that may be desired, and for observing the temperature at which dew is formed with precision. Daniell's hygrometer (fig. 20) consists of a glass tube bent at right angles at two points, with a bulb at each extremity. One of the bulbs is nearly filled with ether, into which is plunged the ball of a delicate thermometer. The other bulb is covered with muslin; this being wetted with a few drops of ether, evaporation of the ether takes place, which quickly cools the bulb, and thus condenses the vapour of the ether which is within. In consequence of this the ether inside the other bulb evaporates, and its temperature being thereby reduced, *a ring of dew begins to be formed outside the bulb.* At this instant the thermometer inside is read, and the reading gives the dew-point of the air at the time. At the same time the temperature of the air is given by

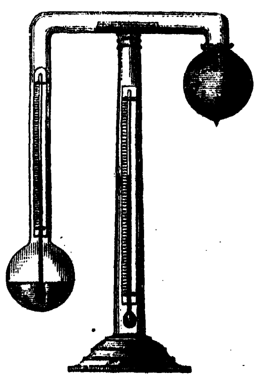


Fig. 20.

the thermometer which is freely exposed to the air on the upright stand. This is the simplest and cheapest of the two hygrometers, but Regnault's requires less time in making the observations. Owing to the trouble and expense attending the use of all hygrometers which give the dew-point directly by condensation, another hygrometer has come into general use by which the dew-point may be determined indirectly by evaporation—viz., the *dry-and-wet-bulb thermometers.*

252. This hygrometer (fig. 21) consists of two mercurial thermometers, which, being placed side by side, would indicate the same temperature. The dry-bulb is a common thermometer, intended to show the temperature of the air. The wet-bulb is also a common thermometer, having its bulb covered with a piece of thin muslin, from which pass a few threads of darning cotton or narrow strip of muslin into a small vessel containing rain-water. Water rises by capillary attraction from the vessel to the muslin, thus keeping it constantly wet. When the air is dry evaporation proceeds rapidly from the muslin, and on account of the heat lost by evaporation the wet-bulb indicates a lower temperature than the dry-bulb. But when the air is damp, evaporation is slower, and the difference between the two thermometers becomes smaller; and when the air is completely saturated evaporation ceases, and the two thermometers indicate the same temperature.

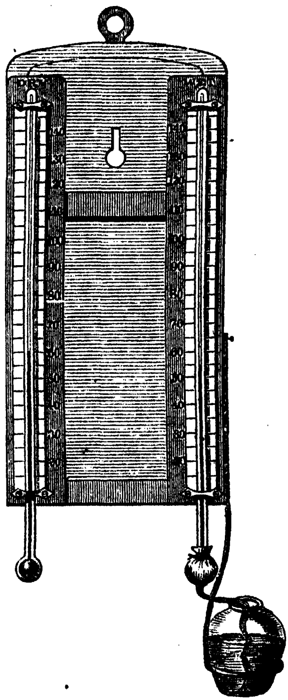


Fig. 21.

253. Some precaution is required in taking the observations when the temperature of the air is below 32°. In such cases, if the wet-bulb reads higher than the dry-bulb, the observation should not be recorded, the instrument being for the time not in proper working order. If the water on the muslin is frozen, the readings are quite good, since evaporation takes place from ice as well as from water. But if the muslin be dry, it must first be wetted and

then allowed time to freeze before the observation is taken. A useful rule to observe in frosty weather is, to immerse the bulb and conducting-thread in water after every observation, by which sufficient ice will still be adhering to the muslin at the time of the next observations. When the temperature of the air rises above 32°, the wet-bulb must be plunged into warm water to melt any ice that may remain on it, after which it must be allowed sufficient time to cool before being observed.

254. To keep this instrument in working order one or two things require special attention. Both thermometers must be exactly the same; for if one is filled with mercury and the other with spirit, or if they contain different quantities of the same fluid, the readings will in either case be vitiated. All starch or foreign matter must be washed out of the muslin and cotton. The water used should be pure; for if lime be dissolved in it, the muslin will soon be coated with a calcareous incrustation. Rain or distilled water should be used. The muslin ought to be changed when covered with dust or other impurities, and care should be taken not to touch the muslin with the fingers, otherwise it will get slightly greased, and the capillary attraction be thereby interfered with. The bulbs of the two thermometers should be made to project 1½ or 2 inches below the scales. The thermometers should also be a little apart from each other, and the glass vessel be, as in the figure, as far removed as possible from the dry-bulb. If these directions, trivial though some of them may appear, be not attended to, the observations will lose their value.

255. Since the mean of the temperatures observed at 9 A.M. and 9 P.M. is nearly the mean temperature of the day, these are the hours to be preferred for observing the hygrometer. An additional observation at 3 P.M., when the temperature is at the maximum, is recommended, as showing the greatest dryness of the air during the day.

256. By means of these two observations, *the temperature of the air*, as shown by the dry-bulb, and *the temperature of evaporation*, as shown by the wet-bulb, the following may be either determined or approximated to by means of tables constructed for the purpose:—(1) The dew-point; (2) the elastic force of vapour, or the amount of the barometric pressure due to the vapour present in the atmosphere; (3) the quantity of vapour in a cubic foot of air; (4) the additional vapour required to saturate a cubic foot of air; (5) the relative humidity and (6) the weight of a cubic foot of air at the pressure at the time of observation.

257. The formula of reduction, as deduced from Dr Apjohn's

investigations, is as follows:—Let F be the elastic force of saturated vapour at the dew-point, f the elastic force at the temperature of evaporation (the wet-bulb), d the difference between the dry and wet bulb, and h the barometric pressure, then

$$F = f - \frac{d}{88} \times \frac{h}{30}$$

when the reading of the wet-bulb is above 32°; and

$$F = f - \frac{d}{96} \times \frac{h}{30}$$

when the wet-bulb is below 32°. M. Regnault has determined by carefully-conducted experiments the value of the elastic force of vapour; the results are given in Table V. From this table f is found; and d and h being obtained by observation, F is calculated. From F *the dew-point* is found by using Table V. reversely, and finding the temperature opposite the *elastic force* calculated. To take an example,—Suppose the dry-bulb to read 50° and the wet 45°, and the barometer 29 inches, then $f = .299$ inch (from Table V.); $d = 50° - 45° = 5°$; and $h = 29$ inches. Hence

$$F = .299 - \frac{5}{88} \times \frac{29}{30} = .244.$$

And from Table V. we find the temperature opposite .244 to be 39°.7, which is therefore the temperature of the dew-point when the dry-bulb is 50° and the wet-bulb 45°.

258. To obviate such laborious calculations Mr Glaisher has elaborated a series of factors from the combination of simultaneous observations of the dry and wet bulb thermometers with Daniell's hygrometers. These factors are given in Table VI. We shall find the dew-point of the above example by them. The factor opposite the dry-bulb 50° is 2.06, and the difference between the two thermometers is 5°, therefore

$$2.06 \times 5 = 10.3$$

and hence the dew-point = 50° − 10°.3, or 39°.7, as before.

259. *Relative Humidity.*—In calculating the relative humidity, saturation is assumed as 100, and perfectly dry air as 0. The relative humidity is found by dividing the elastic force of vapour corresponding to the temperature of the dew-point by the elastic force corresponding to the temperature of the air, and multiplying the quotient by 100. Thus elastic force at 39°.7 is .244, and at 50° .361; dividing and multiplying by 100, we find the relative humidity to be 68 when the dry-bulb is 50° and the wet-bulb 45°.

260. Valuable and copious tables for facilitating the process of finding the dew-point, humidity, and other elements specified

above have been published by Mr Glaisher. These tables are indispensable to every practical meteorologist. We shall conclude this chapter with a few remarks on the dew-point, elastic force, and relative humidity.

261. *Dew-point.*—The ascertaining of the dew-point is of great practical importance, particularly to horticulturists, since it shows the point near which the descent of the temperature of the air will be arrested during the night. For when the air has been cooled down by radiation to this point, dew is deposited and latent heat given out. The amount of heat thus set free being great, the temperature of the air is immediately raised. But as the cooling by radiation proceeds, the air again falls to, or slightly under, the dew-point; dew is now again deposited, heat liberated, and the temperature raised. The same process continues to be repeated, and thus the temperature of the air in contact with plants and other radiating surfaces may be considered as gently oscillating about the dew-point. For if it rises higher, the loss of heat by radiation speedily lowers it, and if it falls lower by ever so little, the liberation of heat as the vapour is condensed into dew as speedily raises it. Thus, then, the dew-point determines the minimum temperature of the night.

262. This suggests an important practical use of the hygrometer. If the dew-point is ascertained by it, the approach of low temperatures or of frost may be foreseen and provided against. Thus, suppose on a fine clear spring day, towards evening, that the dry bulb was 50° and the wet 40°; the dew-point at the time is therefore 29°.4. Frost on the ground may then be predicted with certainty, and no time ought to be lost in protecting such tender plants as may be exposed in the open air at that season. If, on the other hand, with a sky quite as clear, the dry bulb was 50°, and the wet 47°; the dew-point being thus 43°.8, no frost need be apprehended. The raising or depressing of the dew-point during the night by a change of wind, is the only circumstance that can happen to interfere with the predictions founded on the hygrometer.

263. *Elastic Force of Vapour.*—In an atmosphere of pure steam its force at the earth's surface is its weight; and in an atmosphere of vapour and air perfectly mixed, the elastic force of each at the surface of the earth is the weight of each. Hence the elastic force of aqueous vapour would be the weight of the whole vapour in the atmosphere over the place of observation; this is expressed in inches of mercury of the barometric column. Thus, suppose the total barometric pressure to be 30.000 inches, and the elastic force of vapour .450 inch, the weight of the dry air or air proper

would be represented by 29.550 inches of mercury, and the weight of the aqueous.vapour .450 inch of mercury. Thus, then, the elastic force may be regarded as representing the absolute quantity of vapour suspended in the atmosphere subject to the modification stated in art. 235. It may also be termed the absolute humidity of the atmosphere. It is greatest within the tropics, and diminishes towards the poles. It is greater in the atmosphere over the oceans, and decreases as we advance inland. It is greater in summer than in winter, and greater at mid-day than in the morning. It also diminishes with the height, but the average rate at which it diminishes is not known. The balloon ascents of Mr Glaisher and other aëronauts have thrown some light on the question. But the number of ascents is by far too small to warrant the drawing of general conclusions as to the *mean rate* of the diminution. The chief point established is, that on particular instances the diminution is generally very far from uniform; different strata are superimposed on each other, differing widely as regards dryness and dampness, and the transition from the one to the other is frequently sharp and sudden.

264. *Relative Humidity.*—This must not be confounded with absolute humidity. Suppose the temperature of the air to be 40°, and, quite saturated with vapour, to be suddenly raised to 50°, without any addition being made to its vapour, its absolute humidity would in either case be the same; but in the former case it would in popular language be said to be very damp, and in the latter case very dry. This essential and palpable difference is expressed by the term *relative humidity*, or more briefly the *humidity of the air*. Thus, in the language of meteorologists humidity of the air means the degree of its approach to complete saturation. When the humidity is 100, the air is completely saturated; if the humidity at 9 A.M. and 9 P.M., when the temperature is about the average of the day, is 73, the air to an inhabitant of Great Britain would feel very dry, 73 being about the lowest mean humidity that occurs in Scotland during May, the driest month. This low humidity is, however, greatly exceeded when the east winds of spring happen to acquire their greatest virulence and dryness. Thus, during last May (1866), at Corrimorny, in Inverness-shire, the dry bulb at 9 A.M. on the 21st was 65°, and the wet 47°, thus giving a humidity of 29, perhaps as low a humidity as has hitherto been observed in the British Islands; and of course later in the day this extraordinary dryness must have been still further increased.

265. In the ocean, at a distance from the land, the humidity is always great, and during the night generally approaches 100. In

the interior of continents it is less, especially in sandy deserts, which allow the rain-water speedily to sink, thus drying the surface, and in rocky countries, which are never wetted more than on the surface. Thus at Djeddah, in Arabia, on 12th March 1866, the humidity was as low as 11. The humidity is greatest during the night, when the temperature is at the minimum; it is also great in the morning, when the sun's rays have evaporated the dew and the vapour has not yet had time to find its way up into the air. And it is least during the greatest heat of the day and for some time thereafter, or before the temperature has yet begun perceptibly to fall.

266. Now, between the vapour present in the air and the temperature of the air there is a vital and all-important connection, which the experiments and researches of Professor Tyndall of London have recently done much to elucidate.

267. *Diathermancy of the Air.*—Bodies possess perfect diathermancy when they allow rays of heat to pass through them freely and unimpeded, or when they absorb none of the rays of heat which fall on them and pass through them. Thus perfectly dry air allows heat to pass through it without being sensibly warmed thereby. But it is otherwise with the vapour of water or with a mixture of vapour and air, which presents an obstruction to the free passage of the heat of solar and terrestrial radiation much in the same way as stones in the channel of a river oppose its course. This is undoubtedly one of the most important and conservative functions of the invisible moisture of the atmosphere. For if the moisture was drained out of it, and its diathermancy thereby rendered complete, the sun's rays would burn up everything by their intolerable fierceness, and during the night the escape of heat by radiation to the cold stellar spaces would be so swift and the cold so intense, that the whole living creation would be blighted by its withering touch. The earth would in truth

> "Feel by turns the bitter change
> Of fierce extremes, extremes by change more fierce,
> From beds of raging fire to starve in ice."

268. It is the imperfect diathermancy of a moist though clear atmosphere, together with its high dew-point, which prevents the temperature of the air from falling to so low a point during the night as happens with a clear, dry atmosphere.

269. Lieutenant-Colonel Strachey has examined the Madras meteorological observations of several years, and compared the elastic force or tension of the vapour with the number of degrees the temperature was reduced by radiation from 6.40 P.M. to 5.40

A.M. In all the cases examined, the sky was either quite or all but quite free from clouds. During 1844, when the tension was 1.00 inch, the temperature fell 2°.7; when the tension was between 1.00 and .90, the temperature fell 4°.5; between .90 and .80, 5°.4; between .80 and .70, 6°.9; and between .70 and .60, 8°.3. A tract of remarkably clear weather occurred from the 4th to the 25th March 1850, during which there were great differences in the tension of vapour. The following results exhibit the dependence of the temperature on the vapour in a clear light:—

TERRESTRIAL RADIATION.

Tension of vapour,	.888	.849	.805	.749	.708	.659	.605	.554	.455
Fall of temp. from 6.40 P.M. to 5.40 A.M.,	6°.0	7°.1	8°.3	8°.5	10°.3	12°.6	12°.1	13°.1	16°.5

SOLAR RADIATION.

Tension of vapour,	.824	.737	.670	.576	.511	.394
Rise of temp. from 5.40 A.M. to 1.40 P.M.,	12°.4	15°.1	19°.3	22°.2	24°.3	27°.0

Hence, then, when the quantity of vapour in the air is great, the escape of heat by radiation is obstructed, and the temperature falls little during the night; but when the quantity of vapour is small, radiation is less impeded, and the temperature rapidly falls. Also when the quantity of vapour is great, since less of the sun's heat reaches the earth's surface, the temperature rises slowly, even although the sky be perfectly clear and the sun shining brightly; but when the quantity of vapour is small the sun's rays have a freer access to the earth, and the temperature rapidly rises. From the above examples, when the tension of vapour was about .840, the daily range of temperature was 19°.5; but when the tension was only about .400, the daily range was 43°.5. Since the temperature is hottest during the day, when the air is driest, and evaporation consequently greatest, it is evident that the extent to which the temperature falls during dry nights owing to the evaporation is comparatively small, and that the cause of night cold is radiation. Further, from observations made at Melbourne, M. Neumayer concludes that the absolute quantity of aqueous vapour in the air is in itself alone not sufficient as a criterion for the degree of radiation; but that the absolute quantity of aqueous vapour, together with a certain temperature, in other words, the relative humidity of the air, influences terrestrial radia-

tion in such a manner that the greater the degree of relative humidity the less is the effect of radiation. In connection with this view, the effect of the dew-point in arresting the descent of the temperature must not be forgotten (art. 261).

270. In mountainous countries, where, on account of their height, much less aqueous vapour is interposed between them and the cold regions of space, radiation, both solar and terrestrial, is least obstructed. It is this which explains the scorching heat that surprises the alpine tourist while travelling over fields of snow under a blazing noonday sun. And it is the same cause, the small amount of vapour in the air, that explains the intense heat experienced in the direct rays of the sun in the polar regions, where Captain Scoresby observed it to melt the pitch on the side of his ship exposed to the sun, while ice was rapidly generated at the other side.

271. When observations with black-bulb thermometers, showing the force of solar radiation in different parts of the world, are stated, they appear at first sight absurd, if not contradictory. Thus at Port Louis, Mauritius, in lat. 20° 9′ 56″ south, the highest reading of the black-bulb *in vacuo* was 125° in 1864, and 130° in 1865. Now in Scotland, a thermometer placed in these circumstances, particularly in the eastern districts, would register higher temperatures than those, during at least six months of the year; and in the case recorded by Captain Scoresby, the heat of the sun's rays in melting the pitch must have been about 130°, that is, as high as occurred in the Mauritius during two whole years. An interesting collection of facts of solar radiation in different latitudes and at different elevations is given in Daniell's 'Essays' (2d ed., p. 208 *et seq.*) From the facts adduced, the conclusion is drawn that the *power of solar radiation in the atmosphere increases from the equator to the poles, and from below upwards.* The explanation which Professor Tyndall's experiments referred to above suggests serves to account for the whole phenomena. It follows that hygrometric observations ought to accompany all observations on solar radiation, so as to render them intelligible.

272. The above considerations explain in part the nervous derangement and general unhealthiness produced by the east wind in spring; for as the air is then very dry, the part of the person exposed to the sun's rays is greatly heated as compared with the part in shadow, and this strain on the physical frame few constitutions except the most robust can bear without positive discomfort. On the other hand, exposure to the sun's rays in the tropics is, on account of the thick screen of vapour above,

not attended with the intense heat which might have been expected.

273. Another most remarkable property of water is, that in all its states, aeriform, liquid, or solid, it possesses extraordinary energy as a radiant of heat. As vapour it throws out its heat into space, and is condensed into the light fleecy cirrus or the heavily charged rain-cloud; as a liquid it pours its heat into space and becomes snow or ice; and as a solid, snow or ice, it still continues to pour its heat into space, thereby causing the intensest cold produced by natural causes on the surface of the earth.

CHAPTER VII.

MISTS, FOGS, AND CLOUDS.

274. MISTS and fogs are visible vapours floating in the air near the surface of the earth. They are produced in various ways,—by the mixing of cold air with air that is warm and moist, or generally by whatever tends to lower the temperature of the air near the earth's surface below the dew-point.

275. During a calm clear night, when the air over a level country has been cooled by radiation, and dew deposited, that portion of the air in contact with the ground is lowered to the dew-point, and thus becomes colder than the air above it. Since in these circumstances there is nothing to disturb the equilibrium and give rise to currents of air, and there being no cause in operation which can reduce the temperature much below the point of saturation, the air within a few feet of the surface remains free from mist or fog. But if the ground slopes the cold air will flow down and fill the lower grounds; and since it is colder than the saturated air which it meets with in its course, it will reduce the temperature considerably below the point of saturation, and thus produce mist, or *radiation fog*, as it is sometimes termed. When a lake, river, or marsh fills up the valley, the air, being thereby more saturated, gives rise to denser fogs; and, on the other hand, when the low grounds are sandy or dry, mist is less frequently produced.

276. When an oceanic current meets a shoal in its course, the cold water of the lower depths is brought to the surface, and in all cases where its temperature is lower than the dew-point of the air fogs are formed over the shoal. For a similar reason icebergs are frequently enveloped in fogs. Analogous to the above is the mist which is sometimes seen to rise from rivers whose temperature is lower than that of the air. Thus the waters of the Swiss rivers which issue from the cold glaciers have a temperature considerably lower than that of the air; consequently they cool

the air in contact with them below the point of saturation, and mist is thereby often produced. Similarly such rivers as the Mississippi, which flow directly into warmer latitudes, and are therefore colder than the air above them, are often covered with mist or fogs.

277. Also when rivers are considerably warmer than the air they give rise to fogs, because the more rapid evaporation from the warm water pours more vapour into the atmosphere than it can hold suspended in an invisible state, and the surplus vapour is condensed into mist. Thus deep lakes and the rivers flowing out of them are in winter generally much warmer than the air, and hence when the air is cold and its humidity great they are covered with fogs. When Sir Humphrey Davy descended the Danube in 1818, he observed that mist was always formed during the night when the temperature of the air on shore was from 3° to 6° lower than that of the stream; but when the sun rose, and the temperatures were brought to an equality, the mist rapidly disappeared.

278. The densest fogs occur in large towns built on rivers during the cold months, the causes which produce fogs being then at the maximum. The denseness of the London November fogs is notorious, giving significance to the capital illustration of 'Punch,' which represented a street-boy springing into the air, exclaiming, "I am monarch of all I survey." Their peculiar denseness is caused by the warmth of the river-bed, increased by the sources of artificial heat which London affords; and by the circumstance that the temperature is falling everywhere, and the humidity therefore great, the vapour of the atmosphere is quickly and copiously condensed by the gently-flowing cold east winds which generally prevail in November.

279. In all these cases fogs are very locally distributed, being confined to the basin of the river or lake where they are formed, and do not extend far up into the atmosphere. There are, however, other fogs that spread over large districts, which are originated under different meteorological conditions. Fogs often accompany the breaking-up of frosts in winter. For when the humid south-west wind has gained the ascendancy, and is now advancing over the earth's surface as a "light air," it is chilled by contact with the cold ground, and its abundant vapour thereby condensed into a widespread mist.

280. Hills and mountains are frequently covered with mist, because the temperature of the air falls with the height. Hence as the warm air is driven up the slopes of the mountain by the wind, it becomes gradually colder, and its capacity for moisture is diminished until condensation takes place, and the mountain is

swathed with mist. Owing to the peculiarity of their temperature (art. 168) forests have a marked effect on the mists as well as on the rainfall of mountainous regions. Mists often appear sooner on the parts of hills covered with trees than elsewhere. This happens especially when the mist begins to form after midday, because then the temperature of the trees is lower than that of the grassy slopes. Mists also linger longest over forests, probably on account of the increased cold arising from the large extent of evaporating surface presented by their leaves when drenched with mist. During his residence at the Cape of Good Hope, Sir John Herschel observed a remarkable illustration of the influence of trees in condensing the vapour of the atmosphere. On the side of Table Mountain from which the wind blew, the clouds spread out and descended very low, frequently without any rain falling, while on the opposite side they covered the mountain in dense masses of vapour. When walking beneath tall fir-trees at the time these clouds were closely overhead, he was subjected to a heavy shower of rain; but on going out from beneath the trees the rain ceased. The explanation he gave of the phenomenon was that the clouds were condensed into rain on the cool tops of the trees. And doubtless the innumerable fine leaves of the fir-trees, adding largely to the surface of evaporation, increased the cold, and thus condensed the vapours into a more copious shower.

281. I am informed by the Rev. Mr Farquharson, Selkirk, that when the atmosphere is very moist and the south-west wind is blowing strongly, a mist or cloud sometimes settles over Bowhill, which lies at the junction of the classic Yarrow and Ettrick, and that the cloud thus formed is subject to great and rapid changes, both as regards its outline and its size. This is a highly instructive observation, considered with reference to the causes which produce the phenomenon. Both valleys lie nearly in the direction of the south-west wind, but the Vale of Ettrick is the more highly wooded of the two; and hence the temperature of the two valleys will, from what has been stated above, be generally different the one from the other. Now, when a steady humid south-west wind is blowing, each will acquire the temperature of the valley down which it has flowed, and be at the same time at or near the point of saturation; and at Bowhill, where the two aërial currents meet and mix together, cloud will be formed, in accordance with the well-known law by which two volumes of air, each saturated but of different temperatures, can when mixed no longer hold all the vapour in suspension; consequently part is condensed into cloud or rain.

282. Extensive fogs also prevail where great differences occur

in the temperature of contiguous regions. Thus promontories running out into the sea are frequently enveloped in mist; for, the land being warmer than the sea in summer and colder in winter, the difference of temperature is generally sufficient to cause mists with the veerings of the wind landward or seaward. The same cause explains the mists and fogs which frequently prevail on the coast. These mists generally occur in the morning and evening, seldom advance far inland, and usually accompany fine weather. There is a weather prognostic current in Elie in Fife, as follows:—

"When Kellie Law gets on his cap,
Largo Law may laugh at that;
When Largo Law puts on his hat,
Let Kellie Law beware of that."

Kellie Law, the lower of the two hills, lies to the north-east of Elie, and Largo Law to the north-west. Hence the mist which covers Kellie Law only is brought by a local, temporary, and superficial sea-breeze from the east, which does not advance so far to the westward as Largo Law; but when Largo Law is involved in clouds, while Kellie Law is yet clear, we may be sure that the south-westerly current, laden with moisture, which has already reached that hill, will speedily advance on Kellie Law and pour down its rain over the district.

283. The British Islands, being bounded by the warm waters of the Atlantic on the one side, and separated from the Continent on the other only by narrow belts of sea, are subject to fogs during winter. For the same reason dense thick fogs are prevalent in Norway, Newfoundland, along the coast of Peru, and in the polar regions. The Gulf Stream is notorious for dense and long-continued fogs, which seriously obstruct the navigation of that part of the Atlantic, particularly at its northern limit, where it meets the polar current. The high temperature of the stream, which is often from 16° to 18°, and sometimes 30°, higher than that part of the sea past which it flows, fully explains the denseness and duration of these fogs.

284. Occasionally the summit of a hill or an isolated peak is wrapped in mist or cloud, while elsewhere the atmosphere is clear; and though a breeze be blowing over the hill, still

"Overhead
The light cloud smoulders on the summer crag,"

apparently motionless and unchanged. This phenomenon is instructive, and is easily explained. The temperature at the top is below the dew-point of the atmospheric current. Hence when the

air rises to this region its moisture is condensed into cloud, which is borne forward over the top of the hill and down the other side, acquiring heat as it descends till it is again dissolved and disappears. Meanwhile its place is constantly supplied by fresh condensations which take place as the current, rising to the height of the cloud, falls below the temperature of saturation. Thus, though the cloud on the top of the hill appears to remain motionless and unchanged, the watery particles of which it is composed are continually undergoing renewal.

285. There is another sort of fog of occasional occurrence, differing from any of the foregoing in several important particulars, which, from its relation to storms, is of considerable importance in meteorology. It would appear to originate from the juxtaposition of the polar and equatorial currents. When these currents flow side by side, fog frequently fills up the comparatively calm space intervening between them. It results from the mixing together of the two currents, the cold of the polar current condensing the vapours of the south-west wind. It sometimes stretches several hundred miles in the form of a long narrow strip. At other times, and more usually, it is a precursor of storms which succeed fine dry weather, during which the wind has been chiefly from the north-east. The south-west wind is seen to prevail in the upper regions of the atmosphere by the direction in which the thin cirrus cloud is blown, some time before it is. felt on the surface of the earth. During this interval the humid equatorial current overlaps the polar current, and the fog which prevails is due to the mixing of the two currents. Hence, in discussing storms, fogs constitute one of the most important elements requiring consideration, and they supply valuable help towards the foretelling of storms.

Clouds.

286. Clouds are visible vapours floating in the air at a considerable height; thus differing from mists and fogs, which float near the surface. Both arise from the same causes.

287. During the warmest part of the day, when evaporation is greatest, warm moist currents are constantly ascending from the earth. As they rise in succession, the moist air is pushed high up into the atmosphere, and losing heat by expansion, a point is at length reached when it can no longer retain in solution the moisture with which it is charged, condensation takes place, and a cloud is formed which increases in bulk as long as the air continues to ascend. As the day declines, and evaporation is checked,

the ascending current ceases, and the temperature falling from the earth's surface upwards, the whole mass of air begins to descend, and the clouds are then dissolved by the warmth they acquire in falling to lower levels. The whole of this process is frequently seen on a warm summer day. In the morning the sky is cloudless, or nearly so; as the heat becomes greater, clouds begin to form before noon and increase in numbers and size, often presenting scenes of unparalleled beauty as, lighted up by the sun into dazzling brilliance, they sail slowly and smoothly across the blue sky; but as the heat diminishes, they contract their dimensions, and gather round the setting sun, lit up with all the fiery splendours of his beams; in a short time they disappear, and the stars come out shining in a cloudless sky.

288. The balloon ascents of Mr Glaisher and other aëronauts, as well as observations of the clouds, show us that the whole atmosphere to a great height is constantly traversed by many aërial currents superimposed on each other and flowing in different, frequently in opposite, directions. Masses of air of different temperatures thus frequently combine together; and since the several portions when mingled cannot hold in suspension the same quantity of vapour that each could retain before they were united, the excess is condensed and appears as cloud.

289. But again, when a dry and heavy wind begins to set in or take the place of a moist and light wind, it generally does so by edging itself beneath the moist wind and forcing it wedgeways into the upper regions of the atmosphere, where condensation rapidly follows, and dense black clouds, often heavily charged with rain, are formed. This is a frequent cause of cloud and rain in Great Britain, when the cold heavy east wind, or polar current, thrusts high up into the air the rain-bringing south-west wind, thus causing it to darken the sky and pour down its surplus moisture in torrents of rain.

290. Currents of air driven up the sloping sides of hills and mountains by the winds, have been already referred to as a frequent cause of the formation of clouds.

291. A very natural inquiry is, How are clouds suspended in the air? The example of a cloud appearing to rest on the top of a hill though a strong wind be blowing at the time (see art. 284) suggests an explanation. The cloud itself may appear stationary or suspended, but the particles of which it is composed are undergoing constant renewal or change. The particles are upheld by the force of the ascending current in which they are formed; but when that current ceases to rise, or when they become separated from it, they begin to fall through the air by their own weight

till they melt away and are dissolved in the higher temperature into which they fall. Hence, as Espy has reasoned, *every cloud is either a forming cloud or a dissolving cloud.* While it is connected with an ascending current, it increases in size, is dense at the top, and well-defined in its outlines; but when the ascending current ceases the cloud diminishes in size and density.

292. When cloud overspreads the sky, the lower surface is for the most part horizontal, or more generally it follows the contour of the earth's surface beneath it. This arises from the high temperature of the air below the cloud, which is sufficient to dissolve the particles as they descend below the level of the cloud.

293. On ascending through this lower stratum of cloud, the temperature is found frequently to rise, and the air to be quite clear of clouds for a considerable thickness. Higher up a second stratum of clouds succeeds, and again another clear space, and so on, cloud and clear sky following each other several times in succession. These phenomena arise from the different currents which are encountered, superimposed over each other and differing in temperature and humidity.

294. The gorgeous appearance clouds occasionally present in balloon ascents, is thus graphically told by Mr Glaisher in describing his ascent from Mill Hill, near Hendon, on 21st August 1862 :—" Twenty-seven minutes after leaving the earth, a white mist enveloped the balloon; the temperatures of the air and dew-point were alike, indicating complete saturation. The light rapidly increased, and, gradually emerging from the dense cloud into a basin surrounded by immense black mountains of cloud rising far above us, shortly afterwards there were deep ravines of grand proportion beneath open to the view. The sky immediately overhead was dotted with cirrus clouds. As the balloon ascended, the tops of the mountain-like clouds were tinged with silver and gold. On reaching their level, the sun appeared flooding with light all that could be seen both right and left, tinting with orange and silver all the remaining space. It was a glorious sight. The ascent still continued, but more quickly as the sun's rays fell upon the balloon, each instant opening to view deep ravines and a wonderful sea of clouds. Here arose shining masses of cloud in mountain-ranges, some rising perpendicularly from the plains with summits of dazzling brightness, some pyramidal, others undulatory. Nor was the scene wanting in light and shade; each large mass of cloud cast a shadow, thereby increasing the number of tints and beauty of the scene."

295.* *Height of Clouds.*—Kaemtz has collected the results arrived at by many distinguished observers, and deduced the

heights between which clouds range as from 1300 to 21,320 feet. This extreme height is, however, much too small, as has been proved by balloon ascents. Thus Guy Lussac, in September 1804, when at the height of 23,000 feet, saw clouds floating apparently at a great height above him; Mr Glaisher has also made the same observation. It is probable that the cirrus cloud is often ten miles above the earth.

296. Clouds are subject to certain distinct modifications from the same causes which produce the other atmospheric phenomena. Hence the face of the sky may be regarded as indicating the operation of these causes, just as the face of man indicates his mental and physical states. The ancient meteorologist was content with discerning the face of the sky in order to predict the coming weather. It is to this chiefly that the weatherwise sailor and husbandman still look in foretelling the weather; and their predictions are frequently more correct than are those made solely from the indications of the barometer and other meteorological instruments. The best system of weather-prediction comprises both methods. Considering, therefore, the importance of clouds, a nomenclature specifying their different modifications becomes necessary, in order that the experience of one observer may be communicated to others. The classification universally adopted is that proposed by Luke Howard, and published by him in 1803.

297. By this nomenclature clouds are divided into seven kinds; three being simple, the *cirrus*, the *cumulus*, and the *stratus*; and four intermediate or compound, the *cirro-cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *cumulo-cirro-stratus* or *nimbus*.

298. *Cirrus Cloud.*—This cloud consists of parallel, wavy, or diverging fibres which increase in any or in all directions. Of all clouds it has the least density, the greatest elevation, and the greatest variety of extent and direction, or figure. It is the cloud first seen after serene weather, appearing as slender filaments stretching like white lines pencilled across the blue sky, and thence propagated in one or more directions laterally or upward or downward. Sometimes the thin lines of cloud are arranged parallel to each other, the lines lying in the northern hemisphere from north to south, or from south-west to north-east; sometimes they diverge from each other in the form of the tail of a horse; whilst at other times they cross each other in different ways like rich delicate lace-work. It is probable that the fine particles of which this cloud is composed are minute crystals of ice or snow-flakes. The duration of the cirrus varies from a few minutes to

many hours. It remains for a short time when formed in the lower parts of the atmosphere and near other clouds, and longest when it appears alone in the sky, and at a great height.

299. The cirrus, though apparently motionless, is closely connected with the great atmospheric currents. It is this intimate connection which has long caused it to be considered a most valuable prognostic of stormy weather, and as such it deserves even more attention than has yet been given to it.

300. Small groups of regularly formed and arranged cirrus scattered over the sky often accompany *fair* weather with light breezes; these do not indicate the approach of a storm for some time at least. Horizontal sheets of this cloud which fall quickly and pass into the cirro-stratus cloud indicate in an unmistakable manner continued *wet* weather. When streaks of cirrus run quite across the sky in the direction in which a light wind happens to blow, the wind will probably soon blow hard, but it will continue in the same direction; in other words, the variable winds and fitful gusts which accompany storms are not likely to be experienced.

301. When the fine threads of the cirrus appear blown or brushed backward at one end as if by a wind prevailing in these elevated regions, the wind on the surface will ultimately veer round to that point. If the direction indicated be from the south-west, whence the storms of Europe come, wind and rain may be expected; and it matters not how fair and settled-like the weather appear at the time, a storm more or less severe is advancing and may be looked for within 30 or 48 hours. When the storm seems past and the sky has cleared, should a few fine cirrus clouds be seen slightly blown back at their eastern extremities, the storm has in all likelihood really past, and fair weather may with some confidence be expected, since the dry polar current has already begun to prevail overhead.

302. But if, instead of this, innumerable groups and streaks of cirrus cover the sky, crossing each other in all directions, and presenting the appearance of skeins of yarn inextricably tangled together, we may be sure that a second storm will shortly follow the one already past.

303. *Cumulus.*—This name is applied to convex or conical heaps of clouds increasing upwards from a horizontal base. They are usually of a very dense structure, are formed in the lower regions of the atmosphere, and are carried along in the current next the earth. The cumulus has been well called the *cloud of the day*, being caused by the ascending currents of warm air which rise from the heated ground. Its beginning is the little cloud not

bigger than a man's hand, which is the nucleus round which it increases. The lower surface remains roughly horizontal, while the upper rises into towering heaps, which may continue comparatively small, or swell into a size far exceeding that of mountains.

304. Saussure attributes their conical shape to the way in which they are formed. For when one fluid is poured through another it makes its way in curved lines. Thus ink poured into water is diffused through it like clouds. The steam from an engine poured into the air diffuses itself as a cloud; and in like manner the vapour poured upward into the air by the heated currents as they ascend is diffused, and being condensed forms the cumulus.

305. When they are of moderate height and size, a well-defined curved outline, and appear only during the heat of the day, they indicate a continuance of fair weather. But when they increase with great rapidity, sink down into the lower parts of the atmosphere, and do not disappear towards evening, *rain* may be expected; and if loose fleecy patches of cloud begin to appear thrown out from their surfaces, the rain is near at hand.

306. *Stratus.*—The stratus is a widely-extended, continuous sheet of cloud, increasing from below upwards. It is properly, and as its name implies, a continuous layer of cloud. It is, besides, the lowest sort of cloud, its lower surface commonly resting on the earth. The stratus may be called the *cloud of night*, since it generally forms about sunset, grows denser during the night, and disappears about sunrise. It is caused by the vapours which rise during the day, but towards evening fall to the earth with the falling temperature; and since during night the cooling of the air begins on the ground and thence proceeds upwards, the stratus first appears like a thin mist floating near the surface of the earth, and thence increases from below upwards as the successive layers of the air are reduced below the point of saturation. It includes all those mists, already described, which in the calm evening of a warm summer day form in the bottom of valleys and low-lying grounds, and then spread upwards over the surrounding country like an inundation.

307. When the sun has risen and shines on the upper surface of the stratus, it begins to be agitated and heaved up in different places into the rounded forms of the cumulus, while at the same time the whole of its lower surface begins to rise from the ground. As the heat increases it continues to ascend, becomes broken up into detached masses, and soon disappears altogether. These appearances indicate a continuance of the finest and serenest weather.

308. *Cirro-cumulus.*—This cloud is composed of well-defined, small, roundish masses, lying near each other, and quite separated by intervals of sky. It is formed from the cirrus cloud by the fibres breaking, as it were, and collapsing into small roundish masses, thus destroying the texture but retaining the arrangement of that cloud. The change takes place either over the whole cloud at once, or begins at one extremity and proceeds slowly to the other; and while the change takes place it generally descends to a lower position in the atmosphere.

309. This very beautiful cloud is commonly known as a "*mackerel sky;*" it occurs frequently in summer, and is attendant on dry and warm weather. It is also sometimes seen between showers, its graceful form and slow easy motion presenting a striking contrast to the dark, heavy rain-clouds below, which drift hurriedly across the sky. But in this case the cirro-cumulus will be found wanting in the settled order which it wears in fine weather.

310. *Cirro-stratus.*—The cirro-stratus partakes partly of the characteristics of the cirrus and stratus. It consists of horizontal or slightly-inclined masses thinned towards a part of the circumference, bent downwards or undulated, and either separate or in groups. Their form and relative position sometimes resemble shoals of fishes. In distinguishing this cloud attention must be paid, not so much to the form, which is very variable, but to the structure, which is dense in the middle and thin towards the edges.

311. It is markedly a precursor of storms, and, from its greater or less abundance and permanence, gives some indication of the time when the storm may be expected. It may generally be seen between storms, occasionally with the cirro-cumulus, and from what then takes place important information may be drawn as to the continuance or non-continuance of the stormy weather then prevailing. For if the cirro-cumulus give way or pass into the cirro-stratus, thus leaving it, as it were, in possession of the field, more wind and rain may be confidently expected; but if the cirro-stratus yield, and the cirro-cumulus prevail, the storm is past, and fair weather may be looked for.

312. Since the cirro-stratus possesses great extent and continuity of substance, with little perpendicular depth, it is the cloud which most frequently and completely fulfils the conditions requisite for exhibiting *Parhelia* or mock-suns, *Paraselenæ* or mock-moons, *Coronæ*, and *Solar* and *Lunar Halos.*

313. *Cumulo-stratus.*—This cloud is formed by the cirro-stratus blending with the cumulus, either among its piled-up heaps or

spreading underneath its base a horizontal layer of vapour. It sometimes appears indistinctly in the intervals of showers. The *distinct* cumulo-stratus is formed when the cumulus becomes surrounded with small fleecy clouds just before rain begins to fall, and also on the approach of thunderstorms. Tennyson has finely described it as it rises in the west :—

> "The wild unrest that lives in woe
> Would dote and pore on yonder cloud,
> That rises upward always higher,
>   And onward drags a labouring breast,
>   And topples round the dreary west,
> A looming bastion fringed with fire."

314. *Cumulo-cirro-stratus, or Nimbus.*—This is the well-known *rain-cloud,* consisting of a cloud, or system of clouds, from which rain is falling. The rain-cloud often has its origin in the cumulo-stratus, which increases till it overspread the sky, and becomes black or bluish-black in colour; but this colour soon changing to grey, the nimbus is formed, and rain begins to fall.

315. Its name, cumulo-cirro-stratus, suggests more accurately the manner of the formation of the rain-cloud. At a considerable height a sheet of cirro-stratus cloud is spread out, under which cumulus clouds drift from the windward; these rapidly increasing unite at all points, forming one continuous grey mass, from which the rain falls. It is evident from this that the whole body of air under the upper sheet of cloud into which the clouds drift must be completely saturated. The breaking-up of the lower grey mass indicates that the rain will soon cease.

316. When a rain-cloud is seen approaching at a distance, cirri appear to shoot out from the top in all directions; and it has been observed that the more copious the rainfall the greater is the number of the cirri thrown out from the cloud.

317. *Observing Clouds.*—In observing clouds, the kind, the direction in which they are carried in both the lower and upper regions of the atmosphere, and the proportion of the sky covered with them, should be noted. In estimating the amount, that portion of the sky from the horizon half-way to the zenith should not be taken into account, because, the clouds being there foreshortened, the estimate formed would be too great. The scale generally adopted in this country is 0 to 10; 0 indicating a clear sky, 5 that it is half covered, and 10 that it is wholly obscured.

318. The mean amount of cloud in the west of Scotland is 7.2 in winter, 6.4 in spring, 6.5 in summer, and 6.8 in autumn; and in the east and interior of the country the amounts are 6.0, 5.8,

6.0, and 6.1. In Shetland the amount of cloud is greater, three-fourths of the sky being the average space covered with cloud. The month most free of clouds is May, owing to the rising temperature and the dry east winds which then prevail. The cloudiest month is December, when the temperature is rapidly falling, and the south-west wind attains its maximum frequency.

CHAPTER VIII.

RAIN, SNOW, AND HAIL.

319. WHATEVER lowers the temperature of the air may be considered as a cause of rain. Various causes may conspire to effect this object, but it is chiefly brought about by the ascent of air into the higher regions of the atmosphere. Moist air-currents are forced up into the higher parts of the atmosphere by colder, drier, and therefore heavier wind-currents getting beneath them, and thus wedgeways thrusting them upwards; and the same result is accomplished by ranges of mountains opposing their masses to the onward horizontal course of the winds, so that the air forced up their slopes is cooled, and its vapour liberated in showers of rain or snow. Moist air-currents are also drawn up into the higher regions of the atmosphere over the area of least pressure at the centre of storms; and in such cases the rainfall is generally very heavy. The temperature of the air is lowered, and the amount of the rainfall increased by those winds which convey the air to higher latitudes. This occurs in temperate regions, or in those tracts traversed by the return trade-winds, which in the north temperate zone blow from the south-west, and in the south temperate zone from the north-west. The meeting and mixing of winds of different temperatures is also a cause of rain, because the several portions in combination are incapable of holding in suspension the same quantity of vapour that each could hold separately. The rainfall is also increased if the prevailing winds arrive immediately from the sea, and are therefore moist; but diminished if they have previously passed over large tracts of land, particularly mountain-ranges, and are therefore dry. Since the quantity of rain is evidently much modified by the temperature of the earth's surface over which the rain-producing winds flow, it follows that sandy deserts, by allowing solar and nocturnal radiation to take immediate effect in raising or depressing the temperature, and forests, by delaying, if not in many cases counteracting, the effects of radiation, have each a peculiar influence on the rainfall.

320. The rain-cloud has been already generally described in articles 313 and 314, but the more specific conditions under which rain is precipitated are the following, as enumerated by M.E. Renou: —1. Two layers of clouds at least; an upper layer, the cirrus, which being at a great height is composed of minute ice-particles at a very low temperature, probably not higher than —40°; and a lower layer, the cumulus, or cumulo-stratus, which has its density increased and its temperature diminished by the descent of the ice-crystals of the cirrus. 2. The temperature of the air at the earth's surface as high as possible. 3. The atmospheric pressure notably lower than in surrounding regions. 4. Regular horizontal currents of air allowing the atmosphere to remain a sufficiently long time in a state of unstable equilibrium. 5. A rapid movement of the air tending to re-establish the equilibrium of temperature and pressure, by mixing together the different layers of the atmosphere. The geographical distribution of rain over the globe is proportioned to the temperature, the humidity, the mean depression of the barometer, the fluctuations in the temperature, and the nature of the earth's surface.

321. The instrument for ascertaining the quantity of rain which falls is called a *Rain-gauge*. Rain-gauges are of various constructions. The simplest is that which consists of a metallic cylinder, from the bottom of which a glass tube, *b c*, divided into inches and parts of an inch, issues, as in fig. 22. It is provided with a funnel inserted within at the top to prevent evaporation, and the rain-water is emptied out by a stop-cock, *d*, at the bottom, or, what is still simpler, by a hole, *a*, fig. 23, pierced in the funnel at the top. As this form of gauge is objectionable from the frequent breaking of the glass tube in time of frost, a float is used instead, which is raised by the water, and a scale is attached to it projecting above the gauge, by which the quantity of rain is measured. This is the gauge, fig. 24, commonly known as Fleming's gauge; it is extensively used in Scotland.

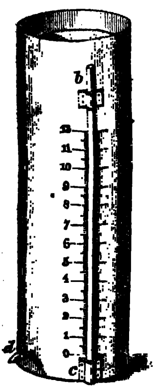


Fig. 22.

Fig. 23.

322. Since this gauge does not admit of very nice measurement, another sort is frequently used, consisting of a receiving-

vessel, and a glass measure of much smaller diameter, which admits of as nice graduation as may be desired. A good specimen of this class is the gauge recommended by Mr Symons, London, fig. 25, in which *b* is the vessel which receives the rain, and *c* the graduated vessel which tells the amount. There being often great difficulty or trouble experienced in replacing the glass measure when it chances to get broken, the late G. V. Jagga Rao, a wealthy zemindar of Vizagapatam, proposed a gauge (fig. 26) in the form of a funnel, having a diameter of 4.697 inches, or a receiving area of 17.33 square inches. Now, since a fluid ounce contains 1.733 cubic inches of water, it follows that for every fluid ounce collected by this gauge the tenth of an inch of rain has fallen. The measure can of course be graduated to any degree of nicety; and it may easily be produced if required. It is also the cheapest rain-gauge, costing only 7s. 6d. when made of copper, and 4s. 6d. when made of tin. Self-registering rain-gauges have been invented by Osler and Crosley; but, being too expensive for general use, they need not be described here.

Fig. 24.

Fig. 26.

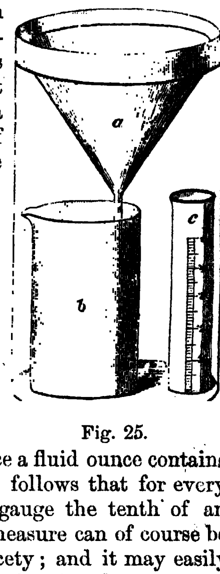


Fig. 25.

323. A most important point requiring attention in the position of the rain-gauge is its height above the ground. Mr Phillips found the rainfall at York for twelve months during the year 1833-34 to be 14.96 inches at 213 feet from the ground; 19.85 inches at 44 feet; and 25.71 inches on the ground. For the past three years an extensive series of observations has been conducted by Colonel Ward at Castle House, Calne, Wilts, with the view of ascertaining the quantity collected at different heights from the ground. The following is the result for last year, 1865:—On a level with the ground, 32.29 inches; at a height of 2 inches, 31.97

inches; 6 inches, 30.76 inches; 1 foot, 30.43; 2 feet, 29.81 inches; 3 feet, 29.88 inches; 5 feet, 29.45; 10 feet, 28.91 inches; and 20 feet, 28.88 inches. In the same year at Greenwich Royal Observatory, 28.55 inches were collected 5 inches above the ground; 22.20 inches at 38½ feet; and 19.28, at 50⅝ feet.

324. The remarkable fact here indicated, that different quantities of rain are collected at different heights, the quantity being greater at the lower levels, has been always confirmed whenever the experiment has been tried. No perfectly satisfactory account has yet been given of this singular phenomenon. The minute watery globules drawn gradually down from the rain-cloud after the falling drops, and their downward course becoming horizontal as they near the surface, the greatest accumulation of such globules is near the surface, where, therefore, they coalesce in greatest numbers into drops heavy enough to fall into, instead of floating past, the gauge; the eddies and currents which prevail most and strongest around isolated objects raised above the ground; the rebound of the finer particles into which many of the drops break as they strike with violence on the ground; and the condensing of the vapour of the atmosphere on the rain-drops as they fall through it, to a large extent account for the phenomenon. The first of these theories, which has been proposed by Mr James Dalmahoy of Edinburgh, would appear to account for the greater part of the excess of rain collected in gauges nearest the surface. The last of the theories, being that proposed by Dr Franklin, and long accepted as sufficient, can only, according to Sir John Herschel, account for one-seventeenth part of the observed excess. The eddy theory advocated by Mr Jevons is interesting, as affording an explanation of many anomalous results obtained; while the remaining theory serves to explain the greater part of the excess observed from one foot downwards to the surface. Since no gauge can ever be constructed and placed so as to measure with perfect accuracy the quantity of rain which falls on the ground, it is only necessary to secure, as far as possible, that all gauges be similarly constructed and placed in similar positions.

325. Rain is the most capricious of all the meteorological phenomena, both as regards its frequency and the amount which falls in a given time. It rarely or never falls in certain places, which are on that account denominated the rainless regions of the globe—the coast of Peru, in South America; the great valley of the rivers Columbia and Colorado, in North America; Sahara, in Africa, and the desert of Gobi, in Asia, are examples: whilst, on the other hand, in such places as Chiloe and Patagonia, it rains almost every day.

326. The quantities of rain which have been recorded as having fallen at one time in some places are truly enormous. In Great Britain, if an inch falls in a day, it is considered a very heavy rain. But in many parts of the Highlands of Scotland, 3 inches not unfrequently fall in one day. On the 5th December 1863, there fell at Portree, in Skye, $12\frac{1}{4}$ inches in 13 hours, during which a continuous cataract appeared to fall from the roofs of the houses ; and on the same day 5.2 inches fell at Drishaig, near Ben Cruachan, in Argyleshire, where also two days afterwards 7.12 inches fell in 30 hours. At Seathwaite, in Cumberland, 6.62 inches fell on 27th November 1848 ; and this enormous fall has been nearly reached six times since that date. But it is in tropical countries especially where the heaviest single showers have been recorded. The following are a few of the most remarkable :—At Joyeuse, in France, 31.17 inches in 22 hours ; at Genoa, 30 inches in 24 hours ; at Gibraltar, 33 inches in 26 hours ; on the hills above Bombay, 24 inches in one night ; and on the Khasia Hills, north-west of Calcutta, 30 inches on each of five successive days.

327. *Rainy Days.*—Rainy days are more numerous in high than in low latitudes. Thus, in the northern hemisphere, from 12° to 43° latitude, the number of rainy days in the year is, on an average, 78 ; from 43° to 46° latitude, 103 ; from 46° to 50° latitude, 134 ; and from 50° to 60° latitude, 161. Considerable discrepancy exists among observations as to the number of rainy days, owing to the want of a generally received definition of what constitutes a *rainy day*. The fall of .01 or $\frac{1}{100}$ inch of rain, as suggested by Mr Symon, might be adopted.

328. *Rainfall within the Tropics.*—At places within the tropics where the trade-winds are blowing regularly and steadily, the rainfall is small, because, these winds coming from higher latitudes, the temperature is increasing, and they are thus rather in the condition of taking up moisture than of parting with it ; and the return trades, which blow above them in the opposite direction, having discharged the greater part of their moisture in the region of calms, are also dry and cloudless. Where, however, they are forced up the slopes of mountain-ranges lying in their course, as on the east of Hindostan, they bring rain in copious showers.

329. *The Region of Calms* is a broad intertropical belt about 5° in breadth, where the north-east and south-east trades, meeting and opposing, mutually destroy each other, and thus produce a calm. This is the region of constant rains. Here the sun almost invariably rises in a clear sky ; but about midday clouds gather, and in a short time the whole face of the sky is densely covered with black clouds, which pour down prodigious quantities of rain.

Towards evening the clouds disappear, the sun sets in a clear sky, and the nights are serene and fine. The reason of this daily succession of phenomena in the belt of calms is, that there the air, being greatly heated by the vertical rays of the sun, ascends, drawing with it the whole mass of vapour the trade-winds have brought with them, and which has been largely added to by the rapid evaporation from the belt of calms; this vapour is condensed as it rises to the line of junction of the lower and upper trades. The discharge is in some cases so copious that fresh water has been collected from the surface of the sea. As evening sets in, the surface of the earth and the superincumbent air being cooled, the ascending currents cease and the cooled air descends; the clouds are thus dissolved, and the sky continues clear till the returning heat of the following day brings round a recurrence of the same phenomena. It will be observed that the daily rains of the belt of calms are to a great extent analogous in their origin and causes to the formation of the cumulus cloud of temperate climates. Since the belt of calms which determines the rainy season within the tropics moves northward or southward with the sun's declination, carrying the trade-winds with it on each side, it follows that there will be only one rainy and one dry season in the year at its extreme northern and southern limits, but at all intermediate places there will be two rainy and two dry seasons, these being at the equator equally distant from each other.

330. This state of things is only strictly applicable to the Pacific Ocean, whose expanse of water, presenting a uniformly radiating and absorbing surface, is sufficiently broad to allow the law to take full effect. But over a great part of the tropics disturbing influences draw the trade-winds out of their normal course, and sometimes produce even a total reversal, as in the case of the monsoons. These winds determine the rainfall of India, and but for them the eastern districts of Hindostan would be constantly deluged with rain, and the western districts constantly dry and arid. As it is, each part of India has its dry and wet seasons, summer being the wet season of the west and interior as far as the Himalaya, and winter the wet season of the east, and especially the south-east. Thus the rainfall at Mahalabuleshwar, in the Western Ghauts, in the four months from June to September, is 242 inches, while during the other eight months it is only 12 inches. At Benares for the same time the quantities are 46 inches and 7 inches. On the other hand, in the east, at Madras, the rainfall for the three months, October, November, and December, is 30 inches, and for the other nine months 19 inches.

331. So far as is known, the heaviest annual rainfall at any place

on the globe is 600 inches, on the Khasia Hills, about 500 inches of which fall in seven months, during the south-west monsoons. This astonishing quantity is due to the abruptness of these hills facing the Bay of Bengal, from which they are separated by only 200 miles of low swamps and marshes. Hence the winds not only arrive heavily laden with the vapour they have absorbed from the Indian Ocean, but, receiving further accessions of moisture in passing over the 200 miles of swamp, they are, so to speak, ready to burst in torrents, even before they are suddenly raised by the hills they encounter into the cooler regions of the atmosphere. At 20 miles farther inland the annual amount is reduced to 200 inches; at 30 miles to 100 inches; north, at Gowahatty, in Assam, it is only 80 inches. In the north-west of the Bay of Bengal, at Cuttack, it is only 50 inches; while in the north-east, in Arracan, being more in the course of the south-west monsoon, the rainfall is swelled to 200 inches. In the following annual amounts the effect of the hills is strikingly shown:—At Madras, 55 inches, but Seringapatam only 24 inches; at Bombay, 75 inches; among the West Ghauts, at Uttra-Mullay, 263 inches; and at Mahalabuleshwar, 254; while at Poonah, more inland, it is only 24 inches.

332. The south-west monsoon discharges from 60 to 80 inches of rain over the parts of Hindostan not bounded by high mountains to the west, before reaching the Himalayas, after which it discharges the greater part of its remaining moisture, 120 to 140 inches, on the outer Himalaya range, at elevations of 4000 to 8000 feet. Thus four times less rain falls annually on the Himalayas, as compared with the Khasia Hills, because (1) they present a less abrupt face to the south, and (2) are separated from the ocean by a sandy burning district, raising the temperature of air above the dew-point, or by hilly ground, which drains the winds of much of their moisture as they pass.

333. The following are a few of the more interesting annual rainfalls in the tropics:—Singapore, 97 inches; Canton, 78 inches; St Benoit, Isle of Bourbon, 163 inches; Sierra Leone, 87 inches; Caraccas, 155 inches; Pernambuco, 106 inches; Rio Janeiro, 59 inches; Georgetown, 100 inches; Barbadoes, 72 inches; St Domingo, 107 inches; Bahamas, 52 inches; Vera Cruz, 183 inches; and Céara, 60 inches. In many places in the interior of continents within the tropics the rainfall is small, being not greater than what occurs in temperate countries, such as the east of Great Britain; thus, as already stated, the fall at Poonah is only 23 inches.

334. *Rainfall in Europe.*—The periodicity of the rainfall disappears as we recede from the tropics, and the times of the year during which it falls are different, the greater quantity falling within the

tropics in summer, but in temperate regions in winter. In respect of the rainfall, Europe may be divided into two distinct regions—Western Europe, extending in a modified degree into the interior of the Continent; and the countries bordering on the Mediterranean.

335. A vast ocean, on the one hand, a great continent on the other, and a predominance of west winds, are the determining circumstances in the distribution of the rainfall over Western Europe. Since the south-west winds, or the return trade-winds, descend to the earth's surface south of Europe, thus bringing this continent within their influence, it follows that the western parts, especially where mountain-ranges stretch north and south, are rainy districts. Hence the wettest regions are Norway, Ireland, the west of Great Britain, and of France, and Spain, and Portugal. At the Stye, in the lake district of England, being, as far as known, the wettest spot in Great Britain, 38.9 inches fell in January 1851; at Drishaig, near Ben Cruachan, 33.2 inches; and at Portree, 32.4 inches in December 1863; and in the same month from 23 to 30 inches at many places in the Scottish Highlands.

336. In the west of Great Britain and Ireland, in the immediate neighbourhood of high hills, the average rainfall is 80 to 150 inches, and in some years it is higher: thus, at Seathwaite, in Cumberland, it was 183½ inches in 1861; and at the Stye, 224½ inches in 1866. At Bergen, in Norway, it is 89 inches; in the Peninsula, at Coimbra, 118 inches; at Oviedo, 74 inches; and at St Jago, 73 inches. In France, it is 51 inches at Nantes and 49 at Bayonne. At places at some distance from hills, and in more inland situations, the annual fall is much diminished. Thus in the west of Great Britain, away from hills, it is from 30 to 45 inches; while in the east of the island it is only from 20 to 28 inches. In France the average is 30 inches; and in the plains of Germany and Russia, 20 inches; while in some parts of Sweden and Russia, it is as low as 15 inches. But in the interior of Europe, in mountainous districts, it rises much above these amounts; thus at the Brocken it is 59 inches, and at St Maria, in the Alps, 104.35 inches.

337. An important distinction between the mode of distribution of the rainfall in the west of Europe and that at more inland places, is that the greater part of the annual quantity of the west falls in winter, whilst in the interior the amount in summer is rather greater than in winter. This peculiarity is shown by the east and west sides of Great Britain. It is caused by the clouds being much lower in winter, by which they are arrested and drained of their moisture by the less elevated hills, thus leaving little to be deposited eastward; but in summer, the clouds, being high, pass above and discharge their moisture in the interior.

For every 10 inches of rain which fall at the following places in winter, there fall in summer respectively, 8½ inches in the west of Great Britain, 11 inches in the east of Great Britain and west of France, 15 inches in the east of France, 20 inches in Germany, and 27 inches in the north and east of Russia.

338. The peculiarity of the rainfall of the basin of the Mediterranean depends on (1) its proximity to the burning sands of Africa, (2) a predominance of northerly winds resulting chiefly from that position, and (3) the Pyrenees and Spanish sierras to the west, on which the south-west winds precipitate their rains before arriving on the north shores of the Mediterranean. In the valley of the Rhone, four times more rain falls in autumn than in summer; and south of the Alps, six times more rain falls with north-east than with south-west winds, being the reverse of what takes place in England. In Italy the quantity of rain diminishes as we approach the south, because south winds get wetter, and north winds get drier as they proceed on their course. Along the Syrian and North African coasts it rarely rains in summer, but frequently in winter. In the valley of the Rhone, the annual fall ranges from 20 inches on the coast to 63 inches at St Rambert, the average being 30 inches. This is also the average of the valley of the Po; but on ascending the long slopes northward to the Alps, it rises, as at Tolmezzo, to 96 inches.

339. *Rainfall of America.*—The rainfall in the west of the American continent is distributed similarly to that of Europe—the quantity being chiefly dependent on the physical configuration of the surface over which the westerly winds blow. In North America the yearly amount increases as we proceed northward; thus at San Francisco it is 22 inches; at Fort Reading, 29 inches; at Fort Oxford, 72 inches; at Fort Vancouver, 47 inches; at Astoria, 86 inches; at Steilacoom (Wash. Ter.), 54 inches; and at Sitcha, in Russian America, 90 inches.

340. But in the United States the manner of the distribution of the rainfall differs greatly from that of Europe. The United States are dependent for their rain, not on the Pacific Ocean, but on the Gulf of Mexico. The high range of the Rocky Mountains in Central America plays an important part in the rainfall; for these mountains present a barrier to the passage of the trade-winds which blow across the Gulf of Mexico, which are therefore, partly on this account, and partly on account of the heated plains of the States, turned or drawn to the northward, and spread themselves over the States, especially over the low basin of the Mississippi. Thus, then, the greatest part of the moisture will be drawn into the valleys where the heat is greatest, and the least

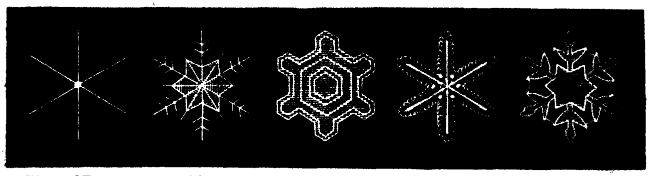
part into the high mountainous regions, where respectively it will be disengaged and fall in rain. If this be the case, then the greatest quantity will fall in the valleys, and the least on the higher grounds—a mode of distribution the opposite of what obtains in Europe. That such is the case the following remarks by Mr Blodget on the rainfall of America, given in the 'Army Meteorological Register,' will show:—"For much the larger area of the United States, and for all portions east of the Rocky Mountains, the distinguishing feature of the distribution of the rainfall *is its symmetry and uniformity* in amount over large areas. The quantity has rarely or never any positive relation to the configuration of the surface, which would identify it with Europe and the North Pacific coasts; and in contrast with these it has a diminished quantity at the greater altitudes generally, and the largest amounts in the districts near the sea-level. It also differs from these districts, and from large land areas generally, in having a larger amount in the interior than on the coast, for the same latitude, at least as far north as lat. 42°." The rainiest districts are Florida, the low flats of the Mississippi, then along the course of its valley, then in Iowa, that remarkable depression at the head of the river; and the least quantities on the Alleghanies, especially their higher parts, and the high grounds of the Missouri district. The following figures give the annual amounts in inches at different places:—In Florida—Pensacola, 57; Fort Brook, 55; and Fort Pierce, 63: in Alabama—Monrosville, 66; and Mobile, 64: in Mississippi—Natchez, 58; and Jackson, 53: in Louisiana—Rapides, 63; and New Orleans, 52: in Tennessee—Nashville, 53: in Georgia—Savannah, 48: in Iowa—Fort Madison, 50. At Athens, in Georgia, south of the Alleghanies, the amount is 36; at Alexandria, in Virginia, also 36; and at Jefferson, in Missouri, 38.

341. In the northern States the quantity diminishes at most places to between 27 and 45 inches, and the mode of its distribution becomes assimilated to that of Europe.

Snow.

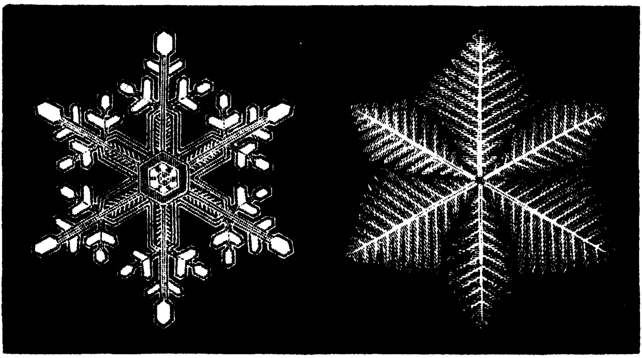
342. *Snow* is the frozen moisture which falls from the clouds when the temperature is 32° or lower. The particles of which snow is composed are crystals, usually in the form of six-pointed stars. About 1000 different kinds of snow-crystals have been already observed, and many of them figured by Scoresby, Glaisher, and others. These numerous forms have been reduced to the fol-

lowing five principal varieties. 1. Thin plates—the most numerous class—comprising several hundred forms of the rarest and



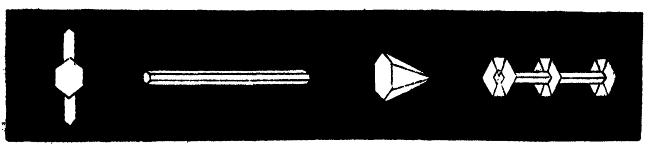
Figs. 27 28 29 30 31

most exquisite beauty (figs. 27 to 33). 2. A spherical nucleus or plane figure, studded with needle-shaped crystals (fig. 34).



Figs. 32 33

3. Six or more rarely three-sided prismatic crystals (fig. 35). 4. Pyramids of six sides (fig. 36). 5. Prismatic crystals, having at the ends and middle thin plates perpendicular to their length (fig. 37). The forms of the crystals of the same fall of snow are



Figs. 34 35 36 37

generally similar to each other. Snow-flakes vary from an inch to 0.07 inch in diameter, the largest being observed when the temperature is near 32°, and the smallest at very low temperatures.

343. The crystals of hoar-frost being formed on the leaves of trees and other bodies which greatly modify the temperature, are on this account not so regularly formed, and are more opaque. It has been observed that each tree or shrub is frequently covered with crystals peculiar to itself.

344. Since the capacity of air for retaining its vapour is diminished as the temperature sinks, it follows that the aqueous precipitation, snow or rain, is much less in polar than in temperate regions.

345. The limit of the fall of snow at any time of the year coincides nearly with 30° N. lat., which includes almost the whole of Europe. On traversing the Atlantic this line rises to lat. 45°, but on nearing America descends to near Charleston in lat. 33°; it rises in the west of America to lat. 47°, and again falls to lat. 40° in the Pacific. It corresponds nearly with the winter isothermal of 52° (Plate III.), because in places where the mean winter temperature is no higher than 52°, the air may be expected to fall during the coldest months occasionally to 32° or lower. Snow is unknown at Gibraltar; at Paris it falls 12 days on an average annually, and at St Petersburg, 170 days.

346. The *white colour* of snow is caused by the combination of the different prismatic rays which issue from the minute snow-crystals. When the crystals are looked at separately, some appear red, others green, purple, and, in short, all the colours of the spectrum, as these are seen in ordinary crystal gasaliers; but when a mass of snow is looked at, these different colours blend into homogeneous white. Pounded glass and foam may be cited as additional illustrations of the prismatic colours blending together and forming the white light from which they had been originally produced. It may be added that the air contained in the crystals intensifies the whiteness of the snow.

347. *Red snow and green snow* have been occasionally met with in the arctic regions and in other parts of the world. These colours are produced by the presence of microscopic organisms, about $\frac{1}{1000}$ inch in diameter, which grow and flourish in the region of eternal snow. It is called *Protococcus nivalis.*

348. The uses of snow are very important; thus, from its loose texture, and from its containing about ten times its bulk of air, snow is a very bad conductor of heat; and thus is an admirable covering for the earth, preserving it from the effects of its own radiation. It not unfrequently happens in times of great cold, that the soil is 40° warmer than the surface of the overlying snow. The flooding of rivers from the melting of the snow on mountains in spring and summer, carries fertility into regions which would otherwise remain barren wastes.

349. Snow is generally from 10 to 12 times lighter than an equal bulk of water; but rare cases have occurred where it was only eight times heavier. Hence in measuring the snowfall, in order to add it to the rainfall, the rule commonly adopted is to measure the depth at a place where it is about the average depth of the district, and take one-tenth as the equivalent of the rainfall. Thus, if the average depth of snow fallen be 5 inches, this would equal 0.5 inch, or half an inch, of rain; if 12 inches of snow, it would be 1.20 inches of rain. This, however, is only a rude way of comparing the snow with the rainfall, owing to its varying compactness. It is accurately measured by thrusting the open end of a cylindrical tin vessel down through the snow to the ground, and melting the snow which it brings up, and then measuring the depth of the water for the rainfall.

350. On the 5th March, 1862, about 9 P.M., the Rev. Charles Clouston, Sandwich, Orkney, observed the snow which was then covering the ground to be rolled up by the wind into masses increasing in size as they moved before it, and blown backwards and forwards in the eddy-wind of the house. The same phenomenon had occurred in February 1847, and was then described by him in the following terms:—"On examination, the masses were all found to be cylindrical, like hollow fluted rollers, or ladies' swan-down muffs, of which the smaller ones reminded me, from their lightness and purity, but most of them were of much greater dimensions and weight than any lady would choose to carry, the largest measured being 3½ feet long and 7 feet in circumference. The weight, however, was not so great as might have been expected from the bulk; so loose was the texture, that one 3 feet long and 6½ feet in circumference was found, on being weighed, to be only 64 lb.; the centre was not quite hollow, but in all there was a deep conical cavity at each end, and in many there was a small opening through which one could see, and by placing the head in this cavity in the bright sun, the concentric structure of the cylinder was quite apparent. They might occupy 400 acres, and I counted 133 cylinders in one acre. A combination of favourable circumstances is required for their formation,—viz., a recent fall of loose snow-flakes in calm weather, as took place on the day previous; a temperature near the freezing-point, so as to give adhesion to the snow, while it is not so warm as to thaw it; and a good breeze of wind to spring up when the other circumstances are favourable to their formation."

351. Sleet appears to be formed from snow-flakes falling through a stratum of moist air at a temperature of 32° or higher. The size of the flakes is caused by the snow particles coming against

each other and uniting by regelation; and they are no doubt further increased by the condensation of vapour on their surfaces as they float down through the moist air. Sleet falls chiefly in winter and in spring, and is very rarely an accompaniment of storms.

352. *Snow-Line.*—The snow-line marks the height below which all the snow that falls annually melts during summer; above this imaginary line lies the region of perpetual snow. No general rule can be laid down for the height of this line, owing to the many different causes which determine it: these are, (1) the exposure of the slope to the sun's rays, and hence, other things being equal, it is higher on the south than on the north side of mountains; (2) the situation with respect to the rain-bringing winds; (3) the steepness of the slope; and (4) the dryness or wetness of the district. Hence the snow-line can only be ascertained from observation. The following are the observed heights in feet, in different parts of the globe:—

HEIGHT OF THE SNOW-LINE ABOVE THE SEA.

	N. Lat.	Height.
Spitzbergen,	78	0
Sulitelma, Lapland,	67	3,835
Kamtchatka,	59½	5,249
Unalaschta, W. America,	56½	3,510
Altai,	50	7,034
Alps,	46	8,885
Caucasus,	43	11,063
Pyrenees,	42¾	8,950
Rocky Mountains,	43	12,467
North Himalaya,	29	19,560
South Himalaya,	28	15,500
Mountains of Abyssinia,	13	14,065
Purace,	2¼	15,381
	S. Lat.	**Height.**
Nevados of Quito,	0	15,820
Arequipa, Bolivia,	16	17,717
Paachata, Bolivia,	18	20,079
Portillo, Chili,	33	1,473
Cordilleras, Chili,	42½	6,010
Magellan Strait,	53½	3,707

It will be observed from this table that, speaking generally, the snow-line from lat. 0° to 20° sinks only a very little; from 20° to 70° it continues to fall equally; but from 70° to 78° it falls with great rapidity.

353. To this general rule there are, however, several noteworthy exceptions. Thus, it is about 4000 higher on the north than on the south side of the Himalayas, owing (1) to the greater depth of snow which falls on the south side; (2) to the greater dryness of the climate of Tibet, which increases the evaporation from the surface of the snow and the heating power of the sun to melt the snow at these great heights; and (3) to the rocks and soil of the north being in a great measure destitute of vegetation, and therefore capable of absorbing more heat than the regions south of the Himalayas, which are covered with vegetation.

354. It is higher in the centre of continents than near the coasts, because the rain is less, and the heat greater; thus, while in the Caucasus it is 11,063 feet, it is only 8950 in the Pyrenees, both places being nearly in the same latitude. Similarly, it is higher on the east than on the west side of continents, as is strikingly shown by Kamtchatka, 5249 feet, and Unalaschta, 3510 feet, situated respectively on the west and east coasts of the North Pacific.

355. South of the equator it rises very considerably from lat. 0° to 18°, and more so on the west than on the east slopes of the Cordilleras, owing to the small quantity of rain and snow which fall on the west side of these mountains. It is as high in S. lat. 33° as in N. lat. 19°; but south of this parallel it sinks very rapidly, owing to the heavy rains precipitated there by the north-west winds which there prevail; so that in the south of Chili it is 6000 feet lower than at the same distance from the equator among the Rocky Mountains of North America, and 3000 feet lower than in Western Europe.

356. The mean temperature of the snow-line varies greatly from the equator to the poles, being at some places 35°, and at others as low as 20°. In the Swiss Alps it is about 25°, and in Norway about 23°.

Hail.

357. The hard pieces of ice which fall in showers are called *hail*. Hail is very different from snow, both in its formation and in the circumstances attending its precipitation.

358. Hailstones are generally of a conical or of a round shape, and when cut across are found to be composed of alternate layers of clear and opaque ice, enveloping a white snowy nucleus, and less frequently of crystals radiating from the centre outwards (figs. 38 and 39). The interior occasionally contains several nuclei, in

which cases the hailstones appear to be a conglomeration of several hailstones, as in fig. 40, which represents one that fell at Bonn on

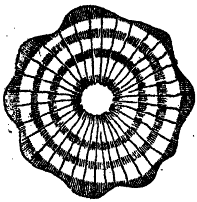


Fig. 38.

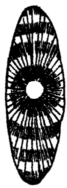


Fig. 39.

Fig. 40.

7th May 1822. The surface is rough, and in the case of the larger hailstones often bristling with small icicles.

359. Hailstones vary much in size, from being as small as shot to several inches in diameter. In August 1813, hailstones the size of eggs fell upon the British army in the Pass of Maga in the Pyrenees; the storm lasted twenty minutes, and was not accompanied with thunder or lightning. On 4th June 1814, hail from 13 to 15 inches diameter fell in Ohio. In Orkney Islands, on the 24th July 1818, during thunder, a very remarkable shower of hail took place; the stones were as large as a goose's egg, and mixed with large masses of ice. In June 1835, hail fully three inches in circumference fell near Edinburgh from a dense cloud during a thunderstorm. On 8th May 1832, an immense mass of aggregated hailstones fell in Hungary, measuring about a yard in length, and nearly two feet in depth. A mass nearly twenty feet in circumference, of an angular shape, and composed of lozenge-shaped pieces congealed together, is said to have fallen in Ross-shire, in August 1849. Masses of this sort are probably formed by regelation after the hailstones have fallen, by which their surfaces are made to adhere together when rolled over each other by the wind.

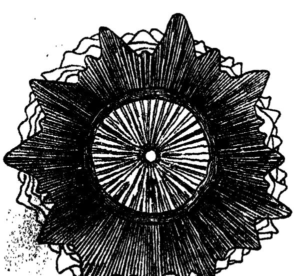


Fig. 41.

360. A hailstone (fig. 41) described by Captain Delcrosse as having fallen at Baconniere in July 1819, was 15 inches in circumference, and had a beautifully radiated structure, showing it to be a single hailstone. On the 8th August

1857 Professor Tyndall saw hail fall among the Alps in the form of perfect spheres of ice, just as if the rain-drops had solidified in their descent. Further particulars regarding these and other meteors will be found in Thomson's 'Introduction to Meteorology,'—a work replete with exact, learned, and curious information of every sort in the different departments of the science.

361. No satisfactory theory of the origin of hail has yet been proposed which can fully explain all the phenomena connected with hailstorms. Hail appears to be formed by a cold current of air forcing its way into a mass of air *much warmer and nearly saturated*, the temperature of the united mass being below the freezing-point. The warm moist air is easily accounted for, since hail generally falls in summer and during the day. The difficulty is to account for the intensely cold current which is sufficient to reduce the warm saturated mass below 32°.

362. In mountainous regions, cold currents from the fields of snow rushing down the sides of the mountains and mixing with the heated air of the valleys are no doubt frequent causes of hail; and we have seen that such places are peculiarly subject to hailstorms.

363. The sudden ascent of moist warm air into the upper regions of the atmosphere, where a cold current prevails at the time, is, in all probability, a common cause of hail. This is confirmed by the circumstances generally attendant on hailstorms—viz., the sultry, close weather which precedes them, the slight but sudden barometric depression, the whirlwinds and ascending currents which accompany them, and the fall in the temperature which follows after the storm has passed off.

CHAPTER IX.

WINDS.

364. WIND is air in motion. The speed of the wind varies from the lightest breath that scarcely stirs the leaf on its branch to the hurricane which, sweeping on in its fury, lashes the ocean into a tempest, strikes down the stateliest trees of the forest, and levels even substantially-built houses with the ground.

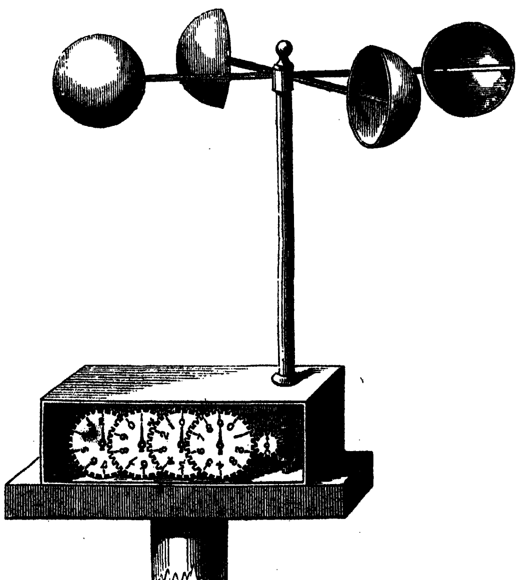


Fig. 42.

365. The force of the wind is measured by *anemometers*, of

which there are different sorts, some measuring the velocity, others the pressure. Of the anemometers which measure the velocity of the wind, the simplest and best is the *Hemispherical-Cup Anemometer*, generally called Robinson's Anemometer, fig. 42. It consists of four hollow hemispheres or cups screwed on to the ends of two horizontal rods of iron crossing each other at right angles, and supported on a vertical axis which turns freely. When placed in the wind the cups revolve; and the arms are made of such a length that when a mile of wind has passed the anemometer, 500 revolutions are registered by the instrument. The accuracy of its construction may be tested by carrying it rapidly through the air on a perfectly calm day the distance of a mile, and noting the number of revolutions made. The number of revolutions is registered by a system of index-wheels set in motion by an endless screw on the upright axis, which are read off in the same way as a gas-meter. The number of miles travelled by the wind during a day, an hour, or any other specified time, is found by multiplying the revolutions made in that time by 2, and dividing by 1000. The rate per hour at which the wind blows at any time is found by observing the revolutions made in, say, two minutes; multiply by 30 and 2 or at once by 60, and divide by 1000. Thus, suppose 800 revolutions were made in two minutes, the velocity of the wind would be at the rate of 48 miles an hour.

366. In this form the anemometer only gives the whole velocity between two observations; it does not register the velocity at any moment. To effect continuous registration an elaborate machinery is required—too complicated to be here described—by which the result is transferred to paper by a pencil, or by photography.

367. The force of the wind is also ascertained by noting the pressure which it exerts on a plane surface of metal perpendicular to the direction of the wind. The pressure is generally given in pounds avoirdupois on the square foot. The instrument is of simple construction, consisting of a plate a foot square acting on a spiral spring, to which an index showing the degree of pressure is attached, the plate being kept perpendicular to the wind by a vane. This is the principle of Osler's anemometer, which, by means of machinery, leaves a pencilling of the pressure of the wind for every instant.

368. The pressure is also measured by Lind's wind-gauge, fig. 43, which consists of a tube half an inch in diameter, in the form of a syphon, one end of it being bent at right angles, so as to face the wind. It turns freely on a vertical axis, and a vane keeps the mouth of it directed to the wind. It is half-filled with water, and when the wind blows into the mouth of the

instrument, it drives the water up the other leg, to which a scale showing the pressure is attached. The zero of the scale is the level at which the water stands when the air is calm. It may also be made to register maximum gusts of wind, by filling into the tube a chemical solution which colours bits of prepared paper, placed at different levels on the scale-limb of the instrument.

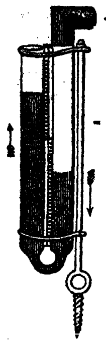


Fig. 43.

369. Table VII. shows for the pressure in pounds on the square foot, the corresponding velocity in miles per hour.

370. Many observers who have no wind-gauge give the force of the wind by estimation. The scale generally adopted in this country is 0 to 6; —0 representing a calm, and 6 a hurricane, or the greatest known force of the wind.* Observations by the scale 0 to 6 are converted into pressure in pounds on the square foot by simple squaring. Sailors use the scale of 0 to 12. Observations on this scale are, of course, reduced to the preceding scale by dividing by 2. In Sweden, Russia, and some other countries, the scale adopted is 0 to 4.

371. But a more important observation of the wind is the direction from which it comes. The direction of the wind is indicated by the point of the compass from which it blows. Those in common use are N., N.N.E., N.E., E.N.E.; E., E.S.E., S.E., S.S.E.; S., S.S.W., S.W., W.S.W.; W., W.N.W., N.W., N.N.W. When thirty-two points are given, an additional one is inserted between each of the above two. If greater accuracy be required, the exact point is indicated by degrees; thus, W. 41° N. means 41° from W. in the direction of N.

* Table of Equivalents for Estimated Force of Wind on scale 0 to 6.

Estimated Force.	Pressure in pounds per sq. foot.	Velocity in miles per hour.	Popular Designation.	Estimated Force.	Pressure in pounds per sq. foot.	Velocity in miles per hour.	Popular Designation.
0.0	0.00	0.0	Calm.	3.0	9.00	42.4	Very fresh.
0.1	0.01	1.4	Lightest breath of air.	3.5	12.25	49.5	
0.5	0.25	7.1	Very light air.	4.0	16.00	56.6	Blowing hard.
1.0	1.00	14.1	Light air.	4.5	20.25	63.6	
1.5	2.25	21.2	Light breeze.	5.0	25.00	70.7	Blowing a gale.
2.0	4.00	28.3	Fresh breeze.	5.5	30.25	77.8	Violent gale.
2.5	6.25	35.4		6.0	36.00	84.8	Hurricane.

372. *Cause of Wind.*—All winds are caused directly or indirectly by changes of temperature. If two neighbouring regions come to be of very unequal temperature from any cause, the air of the warmer region being lighter than the other will ascend and be poured over it from above, while the heavier air of the colder region will flow in below to supply its place. Thus a difference in the temperature of the two districts gives rise to two currents of air—one blowing from the colder to the warmer along the surface of the earth, and the other from the warmer to the colder in the upper regions of the atmosphere; and these currents will continue to flow till the equilibrium is restored.

373. Winds are classified into CONSTANT, PERIODICAL, and VARIABLE WINDS.

374. CONSTANT WINDS.—*The Trade-Winds.*—When the portion of the earth's surface which is heated is a whole zone, as in the case of the tropics, a surface wind will set in towards the equator from both sides; these having united, will ascend, and then separating, flow as upper currents in opposite directions. Hence a surface current will flow from the higher latitudes towards the equator, and an upper current from the equator in the direction of the poles. If then the earth was at rest, a north wind would prevail in the northern half of the torrid zone, and a south wind in the southern half. But these directions are modified by another cause—viz., the rotation of the earth on its axis from west to east.

375. In virtue of this rotation, objects on the earth's surface at the equator are carried round towards the east at the rate of about seventeen miles an hour. But on receding from the equator, this velocity is continually diminished; at latitude 60° it is only about eight and a half miles an hour, and at the poles it is nothing. A wind, therefore, blowing along the earth's surface in the direction of the equator, is constantly arriving at places which have a greater velocity than itself. The wind thus lagging behind, these places will, as it were, come up against it; in other words, an east wind will prevail there. Since, then, the wind north of the equator is under the influence of two forces—one drawing it south, the other drawing it west—it will, by the law of the composition of forces, take an intermediate direction, and blow from the north-east to the south-west. Similarly, south of the equator, the wind will blow from the south-east to the north-west. All observation confirms this reasoning. From the great service these winds render to navigation on account of their steadiness and constancy, they are called the *Trade-Winds*.

376. In the Atlantic, the *north trades* prevail between latitudes

9° and 30°, and in the Pacific, between latitudes 9° and 26°; and the *south trades* in the Atlantic, between latitudes 4° north and 22° south, and in the Pacific between latitudes 4° north and 23½° south. These limits are, however, not stationary, but follow the sun, advancing northwards from January to June, and retreating southwards from July to December.

377. *Region of Calms.*—The region of calms is a belt 4° or 5° broad, stretching across the Atlantic and the Pacific parallel to the equator. It marks the meeting ground of the north and south trades, where they mutually neutralise each other. It is also characterised by heavy rains and severe thunderstorms occurring daily, as already described in art. 329. The position of the calms varies with the sun, reaching its most northern limit, 25° N. lat., in July, and its most southern, 25° S. lat., in January.

378. *Return or Anti-Trades.* — It is clearly established by numerous observations, that while the surface wind within the tropics is directed toward the equator or region of calms, there exist in the upper regions of the atmosphere counter currents flowing from the equator toward the poles. These upper currents, or anti-trades, in their passage to the poles, descend to the earth and become surface currents, beyond the ridge of high barometer, which lies on each side of the tropics (*see* art. 76). These are the prevailing S.W. or W.S.W. winds of the north temperate, and the N.W. or W.N.W. winds of the south temperate zone. The *westing* of these two great equatorial currents is brought about by the same cause that gives *easting* to the trade-winds—viz., the rotation of the earth round its axis. For since the equatorial current flowing north into higher latitudes is constantly arriving at regions having a less rotatory velocity than itself, it will outstrip them and leave them behind. In other words, it will blow over these places as a west wind, and this, combined with its original south direction, produces the S.W. wind. In the same way the direction of the equatorial current in the south temperate zone is N.W.

379. These winds do not constantly prevail in the middle and higher latitudes, being often either counteracted by the polar current flowing southward to the equator, or turned out of their course to restore the atmospheric equilibrium which has been destroyed by storms, or disturbed by the different temperatures which are frequently occasioned by the unequal distribution of land and water.

380. The mean direction of the winds has been calculated from long series of observations made at many places in Europe and North America, from which it appears that the two maximum

directions are the S.W. and the N.E. In other words, the prevailing winds are the equatorial and the polar currents.

381. PERIODICAL WINDS.—*Land and Sea Breezes.*—These are the most general as well as the most readily comprehended of the periodical winds. On the sea-coast a breeze sets in from the sea in the morning; at first a mere breathing on the land, it gradually rises to a stiff breeze in the heat of the day, and again sinks to a calm towards evening. Soon after, a breeze springs up from the land and blows strongly seaward during the night, and dies away in the morning, giving place to the sea-breeze as before. These breezes are caused by the land being heated to a much greater degree than the sea during the day, by which the incumbent air, being also heated, ascends, and the cooler air of the sea-breeze flows in to supply its place. But during night the temperature of the land and air above it falls below that of the sea, and the air thus becoming heavier and denser flows over the sea as a land-breeze.

382. It is interesting to observe the effect of the rotation of the earth on these breezes when the sea-coast lies east and west. Thus on the coast of the Gulf of Lyons, the sea-breeze from the S. veers to the S.W., and dies away in the west; while the land-breeze from the N. gradually turns to the N.E., and dies away in the east. On the coast of Algeria opposite, the sea-breeze veers from N. to N.E., and dies away in the east; while the land-breeze veers from S. to S.W., and dies away in the west. Thus in each place the daily course of the winds may be regarded as rotatory, acquiring their maximum force when they blow from the N. and S., and falling to a minimum in the E. and W.

383. *Monsoons.*—The term *monsoon*, derived from the Arabic word *mausim*, a set time or season of the year, is applied to the prevailing winds in the Indian Ocean, which blow from the south-west from April to October, and from the north-east, or opposite direction, from October to April. The existence of these periodical winds was made known to the ancient Greeks by the Indian expeditions of Alexander the Great; and by the knowledge thus acquired, Hippalus was emboldened to sail across the open sea to Muzeris, the emporium of Malabar. The monsoons are caused by the inequality of heat at different places, and the earth's rotation on its axis; more particularly they arise out of the same circumstances which produce the trade-winds and land and sea breezes, being the combined effects of these two sets of causes.

384. If the equatorial regions had been entirely covered with water, the trade-winds would have blown from the north-east all the year round. But in the south of Asia large tracts of land stretch into the tropics, giving rise to the extensive atmospheric

disturbances for which those parts of the earth are so remarkable. During the summer half of the year, when the sun is north of the equator, the south of Asia and the north of Africa become heated to a much greater degree than the Indian Ocean, which in its turn is warmer than Australia and South Africa. Hence, as the heated air of Southern Asia expands and rises, and colder air from the south flows in to take its place, a general movement of the atmosphere of the Indian Ocean sets in towards the north, thus giving a *southerly* direction to the wind. But as the wind comes from parts of the globe which revolve quicker to those which revolve more slowly, a westerly direction is communicated to it. The combination of these two directions results in the south-west monsoon, which accordingly prevails there in summer. Since, during winter, when the sun is south of the equator, South Asia is colder than the Indian Ocean, which again is colder than South Africa, a general movement of the atmosphere sets in towards the south and west. As this is the same direction as the ordinary trade-wind, the result during winter is not to change the normal direction of the trade-wind, but only to increase its velocity. Thus, while south of the equator, owing to the absence of sufficiently large tracts of land, the south-east trades prevail throughout the year, on the north of the equator, in the east, we find the south-west monsoon in summer and the north-east in winter, it being only in summer and north of the equator that great changes are effected in the direction of the trade-winds.

385. Similar, though less strongly marked, monsoons prevail off the coasts of Upper Guinea in Africa, and Mexico in America. The east and west direction of the shores of these countries, or the large heated surfaces to the north of the seas which wash their coasts, produce, precisely as in the case of south Asia, a south-west monsoon in summer. As might have been expected, the trade-winds off the coast of Mozambique have an easterly direction, and off the coast of West Australia a north-westerly direction. They are also in some degree turned out of their normal direction on the coasts of Brazil, Peru, Lower Guinea, and a few other places. Since these winds veer only through a few points of the compass, they are not true monsoons—the term being strictly applied only to those winds which change their direction so as to blow from opposite quarters at different seasons.

386. About the month of April the north-east monsoon changes into the south-west, and about October the south-west into the north-east. These times depending on the sun's course, and consequently varying with the latitude, are called the *breaking-up of*

the monsoons, and are marked by variable winds, intervals of calm, and furious tempests and hurricanes.

387. Compared with the trade-winds, monsoons play a most beneficial and important part in the economy of the globe. Their great speed and the periodical change in their direction favour increased facility of commercial intercourse between different countries. The full advantages they bring with them are not seen until we consider them in their relations to the rainfall of southern Asia. The fertility of the greater part of this fine region is entirely due to the south-west monsoon, for if the north-east trade-wind had prevailed there throughout the year, Central and Western India, and many other regions, would have remained scorched and barren saharas.

388. VARIABLE WINDS.—As already stated, the direction of the wind is influenced by a great many local causes, such as the nature of the ground, whether covered with vegetation or barren; the physical configuration of the surface, whether level or mountainous; and the vicinity of the sea or of lakes. Within the tropics these local influences are generally overpowered by the great atmospheric currents which prevail there in all their force. But in temperate regions, owing to the diminished force of the permanent winds, there is almost a constant warfare waged between them and the temporary winds arising from local causes. It is beyond the scope of this work to show the peculiar modifications to which the permanent atmospheric currents are subject by local influences in different countries, the question belonging rather to discussions of the climates of different countries.

389. It was remarked by Lord Bacon and other writers, both in Europe and America, that the wind more frequently veers with the sun's motion, or passes round the compass in the direction of N., N.E., E., S.E., S., S.W., W., and N.W., to N. This follows in consequence of the influence of the earth's rotation in changing the direction of the wind. Dové has the merit of having, from Hadley's principle, propounded the *law of rotation of the wind*, and proved that the whole system of atmospheric currents, the permanent, periodical, and variable winds, obey the influence of the earth's rotation.

390. An important characteristic of winds is their quality, being dry or humid, warm or cold, according to their direction, and the nature of the earth's surface over which they have passed. Thus in the northern hemisphere southerly winds are warm and moist, while northerly winds are cold and dry; and in the southern hemisphere *vice versa*. In Europe westerly winds are moist, and easterly winds are dry; while in North America north-easterly are

cold and humid, and north-westerly winds cold and dry. In certain parts of the earth circumstances occur at stated seasons intensifying these effects, and causing excessive drought, heavy rains, great cold, or great heat.

391. *Puna Winds.*—To the east of Arequipa in Peru there is a barren table-land high up among the mountains, called the Puna, which, for four months of the year, is swept by cold arid winds. These winds are part of the south trade-winds, which, after having crossed the lofty range of the Cordilleras, are cooled and parched to a degree that has perhaps no parallel in any other country in the world. The inhabitants, in travelling, find it necessary to protect their faces from the glare and heat of the day, and from the intense cold of the night. The drying qualities of the Puna wind are so excessive, that when a mule happens to die in crossing the plains, it is turned into a mummy in a few days. It was in this district that the ancient inhabitants of Peru preserved their dead.

392. *The East Winds of Great Britain.*—These winds prevail, as is well known, in spring. They are always dry, but in some years, as in May 1866, they reach an almost unprecedented dryness, such low humidities as 44, 37, and even 29, having been observed at many places in Scotland at nine in the morning. The deleterious influence of the east wind is shown not only in the discomfort and uneasiness it gives to the less robust amongst us, but also to the largely increased number of deaths from consumption and brain diseases which it causes.

393. In explaining the east winds of spring, it is only necessary to show why, during that season, the atmospheric pressure is more frequently higher to the north-east of Great Britain than during the other seasons; for they are simply the flowing away of the air from a higher to a lower pressure to restore the equilibrium. From September to March, when the sun is south of the equator, the air of the southern hemisphere, being warmer than that of the northern, expands, and by reason of its expansion part flows over into the northern hemisphere. Hence there is a greater accumulation of dry air north of the equator in winter than in summer. The excess of air is greatest in regions such as the north of Russia, where the greatest degree of cold is experienced, because the air, becoming denser on account of its low temperature, tends to settle there. If we consider only the dry air of the atmosphere, the mean pressure at St Petersburg in winter is 29.840 inches, and in summer 29.512 inches. There is thus a difference of 0.328 inch between the winter and summer pressure at St Petersburg. At Catherinenburg, in the Ural Mountains, the difference is 0.457.

This fact may be made more impressive by saying that there is conveyed away from St Petersburg during summer a stratum of air about 320 feet in thickness. When the sun has begun markedly to heat the air in the northern hemisphere in spring, part flows back into the southern hemisphere. But what influences the east winds more immediately is the heating of the north of Africa and south of Europe and Asia, by which the superincumbent air expanding flows upwards, *thus setting in motion an indraught of air from the north of Russia to take its place.* This northerly current marked out by a high atmospheric pressure generally holds its course through the centre of Europe; and it is a tributary, so to speak, from this current, pouring its dry pestiferous air westwards over Great Britain, which constitutes the east wind.

394. *Simoom* (otherwise written simoun, semoun, samoun, samun), or sambuli, a name derived from the Arabic *samma*, signifying hot, poisonous, or generally whatever is disagreeable or dangerous, is applied to the hot suffocating winds which are peculiar to the sandy deserts of Africa and Western Asia. In Egypt it is called *khamsin* (Ar. fifty), because it generally continues to blow for fifty days, from the end of April to the time of the inundation of the Nile.

395. Owing to the great power of the sun's rays, the extreme dryness of the air, and the small conducting power of sand, thus causing the accumulation of heat on the surface, the superficial layers of sand in the deserts of Africa and Arabia often become heated to 200° F. to a depth of several inches. The air resting on this hot sand becomes also highly heated, thus giving rise to ascending currents; air consequently flows towards these heated places from all sides, and, the different currents meeting, small cyclones or whirling masses of air are formed, which are swept onward by the wind prevailing at the time. Since the temperature, originally high, is still further raised by the heated grains of sand with which the air is loaded, it rapidly increases to a degree almost intolerable. In the shade, it was observed by Burckhardt in 1813 to have risen to 122°; and by the British Embassy to Abyssinia in 1841, to 126°. It is to the parching dryness of this wind, its glowing heat, and its choking dust, and not to any really poisonous qualities it possesses, that its destructive effects on animal life are to be ascribed.

396. The approach of the simoom is first indicated by a thin haze along the horizon, which rapidly becomes denser, and quickly overspreads the whole sky. Fierce gusts of wind follow, accompanied with clouds of red burning sand, which often present the appearance of huge columns of dust whirling forward. Thus vast

mounds of sand are transported from place to place by the terrible energy of the tempest. By these mounds of sand, large caravans are frequently destroyed; and even great armies have been overwhelmed by them, as in the case of Cambyses, who was overtaken by the simoom on his march through the desert to pillage the temple of Jupiter Ammon, and perished with 50,000 of his troops. The destruction of Sennacherib's army is supposed to have been caused by the simoom. The simoom generally lasts from six to twelve hours, but sometimes for a shorter period.

397. Hot winds from Africa are felt in neighbouring regions, where they are known under different names. They are subject to important modifications by the nature of the earth's surface over which they pass. The *Sirocco* blows occasionally over Sicily, South Italy, and adjoining districts. It is a hot moist wind, receiving its heat from the Sahara, and acquiring its moisture in its passage northward over the Mediterranean. It is the plague of the Two Sicilies; and while it lasts, a haze obscures the atmosphere, and so great is the fatigue which it occasions, that the streets of Palermo become quite deserted. This wind sometimes extends to the shores of the Black and Caspian Seas, and to the steppes beyond the Volga, the seat of the dreaded rinderpest, where, by its blighting touch, vegetation withers and dries up, and thousands of cattle are cut off. It is called the *Samiel* in Turkey, from its reputed poisonous qualities.

398. The *Solano* of Spain is a south-east wind, extremely hot, and loaded with fine dust. It prevails at certain seasons in the plains of Mancha and Andalusia, particularly at Seville and Cadiz. It produces dizziness, and heats the blood to an unusual degree, causing great uneasiness and irritation; hence the Spanish proverb, "Ask no favour during the solano."

399. The *Harmattan* of Guinea and Senegambia belongs to the same class of winds. It is a periodical wind blowing from the dry desert of Africa to the Atlantic, from N. lat. 15° to S. lat. 1°, during December, January, and February. It blows with moderate force, is often highly charged with fine particles of dust, and since under its influence no dew falls, vegetation grows languid and withers.

400. The *Pampero* is a wind which blows chiefly in the summer season from the Andes across the pampas of Buenos Ayres to the sea-coast. It is thus a north-west wind, or part of the anti-trade of the southern hemisphere, and in this respect it is analogous to the stormy winds which sweep over Europe from the south-west. But since it blows from the Andes over the South American continent, it is a dry wind, frequently darkening the sky with clouds of dust, and drying up the vegetation of the pampas.

401. In the south of Europe north winds are notorious for their violence. The great differences of the temperature of the Alps, the Mediterranean, and Africa explain them; and when the polar current, with high atmospheric pressure generally accompanying it, is descending at the same time over Europe, the effect is greatly heightened. Of these the most noted is the *Bora*, which, descending from the Julian Alps, sweeps over the Adriatic—the bitterly cold tempestuous wind of that much-vexed sea. It is probably the Euroclydon of the Acts. The *Mistral* is a steady violent north-west wind which blows from France down on the Gulf of Lyons. There are other winds of a stormy character peculiar to different parts of the Mediterranean, such as the *Levanter* in the east. The heating of the Sahara in summer causes a general and continued flow of the cooler air of the Mediterranean to the south to take the place of the heated air which rises from the sandy desert. These are the *Etesian winds* of Southern Europe.

CHAPTER X.

STORMS.

402. STORMS are violent commotions of the atmosphere, occurring in all climates, and differing from other atmospheric disturbances in their destructive power and the extent over which they spread. There is, perhaps, no question in physical science in which there has been so large an admixture of speculation with fact as in the attempts made to reduce the phenomena attendant on storms to general laws; the reason being, that meteorological observations were too few in number, and too far apart, to enable any one to give the atmospheric pressure, the general course of the winds, the temperature, and the rainfall, without drawing largely on conjecture. Now, however, owing to the growing popularity of meteorology, and the countenance happily given to it by most civilised nations, sufficient data may be obtained for a fuller and more satisfactory statement of the question. I shall first state the chief facts of observation regarding storms as obtained from synchronous charts of the weather over a considerable portion of the globe; and as such charts present the principal elements of the weather at a given instant, they may be regarded as successive photographs of storms in their passage across the earth's surface.

Storms of Europe.

403. I have charted about a hundred European storms, laying down in all cases the isobarometric lines, or lines of equal atmospheric pressure,* and the direction and force of the winds, and, in a

* In place of lines of equal barometric pressure, many Continental meteorologists give lines of equal barometric disturbance—that is, the difference between the barometer on the particular day, and the mean height of the barometer for the place and season. As this method can only suit a limited space of the earth's surface, it ought to be discarded. Thus, suppose on

great many instances, the lines of equal thermometric disturbance, and the rainfall, cloud, and clear sky. The conclusions drawn from these have been compared with the daily charts of the weather published in Le Verrier's 'Bulletin International,' so that the results which will be stated as applicable to the storms of Europe are based on a sufficiently large number of instances. Plate IV. is given as illustrative of the general features of these storms. It is a synchronous chart of Europe, giving, from observations made at upwards of one hundred places scattered over that continent, the atmospheric pressure and direction and force of the wind at 8 A.M. of the 2d of November 1863, from which are shown the position and character of two storms passing over Europe at that time. The isobarometric lines, or lines showing where at that hour the height of the barometer at the level of the sea was the same, are given for every two-tenths of an English inch in the difference of the pressure. Hence, where these lines approach near each other, or crowd together, the difference of pressure, or the atmospheric disturbance, was greatest; and least where they are most apart—a distinction of the utmost importance in determining where the storm may be expected to rage with greatest fury. The force of the wind is shown (1) by plain arrows, $\longrightarrow$, which represent light and moderate winds; (2) by arrows feathered on one side only, , which represent high winds; (3) by arrows feathered on both sides, , which represent strong gales, storms, or hurricanes; and by ⊙ representing a calm. The arrows are represented as flying with the wind.

404. The normal atmospheric pressure over Europe at the level of the sea may be stated roughly at 29.9 inches. When, therefore, the barometer falls below 29.9, the equilibrium of the atmosphere is more or less disturbed in proportion to the extent of the fall, and it is within this *area of low barometer* that storms occur. Hence, by tracing these low pressures as they advance over the earth's surface from day to day, we trace at the same time the progress of the storms.

the 15th January the barometer in Western Europe was the average of the month—viz., in Iceland, 29.515 inches; in London, 29.956; at Algiers, 30.276, &c.; then, by the method of equal barometric disturbance, these pressures would all be reckoned as 0—that is, no barometric disturbance would be indicated. But under such circumstances there *would be very great barometric disturbance, which would occasion a general flow of the atmosphere from the very south of Europe northward toward Iceland.* Hence no method but that of reduction of barometric observations to sea-level represents *the whole of the disturbing force* at any time prevailing over wide areas. Except at very great heights, the reduction to sea-level by the usual methods may be accepted as close approximations.

405. *Form and Extent of Storms.*—The circular isobarometric lines on the chart represent very accurately the shape storms generally assume. The area of every storm is either circular or elliptical, and when elliptical, the major axis of the ellipse seldom exceeds twice the length of the minor axis. Rarely in Europe, though less rarely in America, the form of storms is more elongated. The outline is occasionally very irregular, but in every such case the storm will be found to have parted into two, or more rarely three, distinct storms, which remain separate for some time, and afterwards reunite. Sometimes, however, they continue separate, and diverge, one taking one direction, the other a different. The circular form of storms, which an examination of some hundreds, especially in Europe, proves to be their general characteristic, is a most important feature, whether as determining practical rules for the guidance of sailors in storms, or for the foretelling of storms at particular seaports. Observation shows that the longer axis of the storm is almost always coincident with the direction in which the storm happens to be moving at the time. The extent over which storms spread is very variable, being seldom less than 600 miles in diameter, but oftener two or three times that amount, or even more. Thus the storm in the chart which had at that time its centre at Liverpool, extended in one direction at least as far south as Bordeaux, or 600 miles. Its diameter was therefore about 1200 miles, or about the average extent. Sometimes even the whole of Europe is involved in a single storm at one time.

406. The area of storms is by no means constant from day to day, but varies in size, sometimes expanding and sometimes contracting. And it is worthy of remark that when a storm contracts in area, the central depression gives signs of filling up, and the storm of dying out. Thus the storm which was at Liverpool on 2d November had, on arriving at Jutland on the following morning, contracted to one-fourth part of its former diameter, and the central depression, instead of 28.9 inches, was now only 29.3 inches. On the other hand, when the storm increases in extent, the central barometric depression becomes deeper, the storm increases in violence, and occasionally is broken up into two, or even three, depressions, which become separate storms, with the wind circling round each.

407. *Direction in which European Storms advance.*—It may be premised that by the direction of a storm is meant, not the direction of the wind, but the path followed by the centre of disturbance, as shown by the lowest barometric pressure. About half the storms of middle and northern Europe travel from the south-west

toward the north-east, and nineteen out of every twenty, at least, travel toward some point in the quadrant of the compass from the north-east to the south-east. In Plate IV. the two heavy hacked lines represent the track of the centre of each of the storms. Thus the storm which on the morning of the 2d November 1863 was in the north of Sweden, had arrived thither from the west of Ireland and Shetland. Its course had thus been *from south-west to north-east.* The other storm, the centre of which was at Liverpool on the 2d November, had advanced from the south-west of Ireland; on the two following days it continued its *eastward* course to Denmark and the Baltic Sea. The first of these directions is by far the most general, and the second the next most common. Some storms, however, travel toward the south-east, over Great Britain, Austria, and the Black Sea, into Asia; of this class was the disastrous storm of November 1854, which inflicted so much damage on the British and French fleets during the Crimean war. Others descend over the North Sea, Germany, Austria, and Italy, thus following a course from north to south. From the 27th to the 30th March 1864 a storm passed successively over the Bay of Biscay, Gulf of Lyons, Corsica, Croatia, the valley of the Theiss, Warsaw, Dantzic, and the south of Sweden; its track was, therefore, semicircular. These two directions are of comparatively rare occurrence.

408. The least common, or rather rarest, direction in which storms travel, is toward some westerly point. Thus the great snowstorm which occurred in Europe in January 1836, and which has been admirably traced and described by Professor Loomis of America, began, as the barometric curves conclusively prove, in the north-east of Russia, and thence proceeded south-west to the Swiss Alps, where its westward course would appear to have terminated. A few other storms might be mentioned, particularly during winter and spring, which have advanced from eastern or north-eastern Russia *westward* to Norway or Denmark, where generally their western course is arrested; they then retreat on their course to the east. Hence, then, though the weather changes of Europe generally advance from west to east, it is a mistake to suppose that this is always the case; and weather-prediction proceeding on this assumption must occasionally lead to error. Further, all the weather changes which conspire to produce the dry east winds in the British Islands are instances of weather changes advancing in a westerly direction.

409. But again, storms have been repeatedly observed to remain stationary for several days in succession over the Bay of Biscay; and occasionally, though less frequently, over the Gulfs of Bothnia

As bearing on this interesting point, I have calculated the mean monthly range of the barometer at about eighty places in Europe, for the last eight years. The lines of equal annual disturbance lie in a direction from W.N.W. to E.N.E., of which the following indicate the position of a few :—

	Inch.		Inch.
Bayonne,	.746	Kremsmünster (Austria),	.721
Brest,	1.005	Warsaw,	.920
Bristol,	1.138	Dorpat (Russia),	1.132
Galway,	1.215	Christiania,	1.229
Stornoway,	1.355	Shetland,	1.304

In July these lines lie from south-west to north-east; but in winter the direction is nearly due east and west, the mean monthly barometric range in Orkney being 1.712 inches, and at St Petersburg, 1.797; at Dublin, 1.421, and at Königsberg, 1.474; and at Bayonne, .926, and at Trieste, .933. As regards Great Britain, it is probable that the centres of the majority of storms pass to the north of it in summer, but in winter a considerable number pass across it.

415. *Relations of the Temperature and the Dew-point to Storms.*—The temperature increases a few degrees at places towards which and over which the front part of the storm is advancing, and falls at those places over which the front part of the storm has already passed. In other words, the temperature rises as the barometer falls, and falls as the barometer rises. Generally the temperature in advance of the storm is above the average, and in the rear of the storm below it; but if it should chance to be considerably above the average in advance of the storm, it may still be above the average when the storm has passed, though lower than it was before. If the temperature begins soon and markedly to rise after the storm has passed, a second storm may be expected in a short time. In front of a storm the dew-point is high, in the rear of it low. This state of things is not what is merely due to the high temperature in the one case, and to the low temperature in the other; for, along with the high dew-point there is great humidity, and along with the low dew-point a small humidity. To express this in popular language—before the storm, the air is close and warm (for the season); but after the storm has passed the air becomes cold and dry.

416. *Relations of Rain and Cloud to Storms.*—When the barometer has been falling for some time, clouds begin to overspread the sky, and rain to fall at intervals; and as the central depression approaches, the rain becomes more general, heavy, and continuous. After the centre of the storm has passed, or when the barometer

has begun to rise, the rain becomes less heavy, falling more in showers than continuously; the clouds break up, and fine weather, ushered in with cold breezes, ultimately prevails. The rainfall is generally proportioned to the suddenness and extent of the atmospheric depression at the place where it falls.

417. *Observations of the Wind.*—First, *as to the direction of the wind.* If the winds in the storm of the 2d November be attentively examined, they will be observed whirling round the area of low barometer in a circular manner, and in a direction contrary to the motion of the hands of a watch, with—and be this particularly noted—a constant tendency to turn inwards towards the centre of least pressure. The wind in storms neither blows round the centre in circles, nor does it blow directly towards that centre, but takes a direction nearly intermediate, approaching, however, nearer to the direction and course of the circular curves than of the radii to the centre. The greater the force of the wind is at any place, it will be observed to approach the more nearly the direction here indicated. And where the direction of the wind differs to any material degree from this general law, it is light, and consequently more under local influences which turn it from its course. Thus the centre of the storm being near Liverpool, the direction of the wind is S.W. at Paris, S. at Yarmouth, N.E. at Silloth, N. at Dublin, and N.W. at Cork. Hence in this storm the winds circulate round the centre of least pressure; or, to speak more accurately, THE WHOLE ATMOSPHERIC SYSTEM APPEARS TO FLOW IN UPON THE CENTRE IN AN IN-MOVING SPIRAL COURSE. This rotatory peculiarity is common to all European storms that I have yet examined, and I have not yet seen any exception to it; and it should be particularly noted that this is not a theory or mere opinion, but a simple statement of what has been invariably observed.

418. Professor Taylor has the merit of having first applied Dove's law of rotation to explain the direction of the rotation of storms round their centre. This may be explained by referring to the storm of the 2d November. On that morning, the pressure over England being much less than in surrounding countries, if the earth had been at rest, air-currents would have flowed from all directions to England, in straight lines. The earth, however, is not at rest, but revolves from west to east; and as the velocity of rotation diminishes as the latitude increases, it is evident that the current which set out, say from Lyons to the north, would, on account of its greater initial velocity when it arrived at Paris, blow no longer directly to the north, but to a point a little to the east of north; in other words, it was no longer a south, but a south-west wind. Again, since the current from the north of

Scotland had a less velocity than those parts of the earth's surface on which it advanced, it lagged behind, and, consequently, by the time it arrived at Silloth in the north of England, had changed from a north to a north-east wind. Similarly the north-west current changed to a north, the south-west to a west, &c. The west and east currents, since they continued in the same latitude, would have blown in the same direction, if they had not been disturbed by contiguous currents. Hence in a storm the whole system of winds rotates round the centre. As a further confirmation of the correctness of this explanation, it is observed that when a high barometric pressure covers a limited space, *the wind is always observed gently whirling out of this area of high barometer, but in an exactly opposite direction from that assumed when it blows round and in upon an area of low pressure.*

419. Next, *as to the force of the wind.* The rule is simple, and without exception—viz., the wind blows from a high to a low barometer, and with a force proportioned to the difference of the pressures. Hence, where the isobarometric lines crowd together, the violence of the storm is most felt, and where they are far asunder the winds are moderate and light. Thus, from Liverpool to the north of Spain the isobarometric lines are crowded together, and it will be observed that over the intervening region the arrows are feathered; that is, the force of the wind is very great—that it is there, in fact, where the violence of the storm is most felt. On the other hand, from the south of Scotland northward and north-eastward the lines are far asunder, and there the winds, consequently, are light. The storm on the 6th February last (1867) may be adduced as an excellent illustration of the same principle. On that morning the barometer was 28.422 at Christiansund, and 28.375 at Skuddesnaes, both in Norway; 28.254 at Kirkwall, 28.335 at Nairn, and 28.540 at Scarborough and Isle of Man. Hence the differences of pressure being slight over that wide region, the winds were everywhere light, but much rain and snow fell. But south of Scarborough the pressure rapidly increased to 28.776 at Yarmouth, 28.859 at Greenwich, 29.607 at Paris, 30.079 at Bayonne, and 30.420 at Lisbon; consequently, over the whole region from Yorkshire to the north of Spain high winds and stormy weather prevailed—the anemometer at Lloyd's registering a pressure of 35 lb. to the square foot, or a velocity of 84 miles an hour. Since this storm passed eastward—its centre, when passing, being in the extreme north of Scotland—and for some days was preceded by low pressures, it happened that, though in the centre of greatest depression, no stormy weather occurred in North Britain. From this it is evident that a storm is not most

violent where the pressure falls to the greatest extent, but at those places which, during the course of the storm, may at any time happen to lie in a position between very high and very low pressures; such places being in the line of the course down which the air rushes impetuously from the high to the low barometer to restore the equilibrium.

420. *Cause of the Heavy and Frequent Gales in the English Channel.*—During the cold months of the year, when storms are most frequent, the mean atmospheric pressure in Iceland is only 29.52 inches, while in France and N. Germany it is about 29.98; it increases as we proceed southward, till, in the latitude of Algiers, it amounts to 30.27. Further, in Iceland, the pressure is often below 29 inches; whereas south of the Channel it seldom falls below 29.5, even when the centres of storms pass over that region; and when the centres of storms pass over Great Britain, the pressure in France and Spain remains high. It results, therefore, from the position of Great Britain, that north of the centre of storms the wind often scarcely rises to the strength of a gale; but south of the central path of the storm—which generally includes the English Channel—the storm bursts forth in all its fury, that arm of the sea being, as it were, in the aërial rapids of the storm between the high and the low barometer. In forecasting the weather, this consideration ought not to be lost sight of.

421. *Places where Calms prevail.*—As the wind comes near the centre of the storm, it gradually turns round and blows more in the direction of the centre; at the same time it abates in force and then sinks to a lull or calm. Since at this time the atmospheric pressure is unusually low, the foul air imprisoned in the mineral of coal-pits escapes more readily into the air, accompanied with a buzzing sound which miners regard as prognostic of a storm or of heavy rain. Accordingly, it is when the barometer is low that explosions from fire-damp in mines are of most frequent occurrence. Calms and light winds also prevail along the ridge of high barometer, or the region where the barometer is highest, and in receding from which it falls on each side. It may not inaptly be compared with the watershed in physical geography, since from it the wind flows away to places where the pressure is less.

422. *Velocity of the Wind.*—We have stated that the progressive motion of storms varies from 15 to 30, or even, on rare occasions, 45 miles per hour, which measures the time taken in passing from one place to another. But this gives no indication of the violence of the storm, which is determined by the velocity of the wind round the centre of the storm, combined with the on-

ward movement. In Europe it frequently amounts to 60 or 70 miles an hour continuously for some time. At Liverpool, on the 3d December 1863, it blew in intermittent gusts with a speed of 93 miles an hour.

423. *Veering of the Wind.*—It follows from the direction of rotation of storms, that at places to the right-hand side of the track of the centre of the storm the wind shifts in the direction from N.E., by E., S., and W., to N.W., and at places on the left-hand side from N.E. by N. to N.W.

Storms of America.

424. From the general resemblance of the American storms to those of Europe, it will only be necessary to make one or two general remarks regarding them. The storm which passed over the United States during the 19th, 20th, and 21st December 1836, has been very fully detailed by Professor Loomis in a series of five well-executed synchronous charts. This storm extended from north to south about 3000 miles, forming an oval figure whose length was from two to three times its breadth. In every one of the charts the winds are seen circling round the area of least pressure, with a constant tendency to turn inwards towards that area; in other words, in this feature the storm was precisely similar to the storms of Europe. Comparing the southern limit of the storm on the successive charts together, we see that its progressive march was from south-west to north-east, resembling also in this respect the storms of Europe. The temperature, rainfall, snow, cloud and clear sky, were perfectly analogous to the storms of Europe.

425. In the 'Fourth Meteorological Report' issued by the Senate of the United States, Professor J. P. Espy gives 58 synchronous charts illustrating the storms which occurred in America from 1st January 1851 to 8th June 1852. These charts have one very serious defect, viz., the isobarometric lines are not drawn on them; but, instead of these, two hypothetical lines—one, which he calls the line of minimum barometer, passing through those places at which the pressure has fallen to the lowest observed there, but has not yet begun to rise; the other, the line of maximum barometer, passing through those places at which the pressure has risen to the highest attained, and has not yet begun to fall. This mode of representation is, it need scarcely be said, very defective. It makes hypothetical barometric lines usurp the place of lines representing actual observations; and it gives no clue whatever for finding the position of the area of least pressure, the shape of that area, and

the depth of the barometric depression—the essential elements of storms, to which all others are subordinate, since the strength of the wind is proportioned to the difference of pressure. Since, however, the winds and rainfall supply very trustworthy information regarding the position of storms, and their translation from place to place, an examination of these fifty-eight charts leads to the following results:—The storms of America take their rise in the vast plain which lies immediately to the east of the Rocky Mountains, and thence advance, generally in a north-easterly direction, across the United States. The other features of storms—the in-moving spiral course of the winds rotating round and in upon the centre, the high temperature and dew-point in front, and the low temperature and dew-point in rear of storms, the rainfall, cloud, and clear sky—differ in no respect from the storms of Europe. The only noteworthy difference which exists between the storms of the two continents is, that in America they appear to have a more elongated form, and to advance toward the east sideways—that is, the longest diameter is at right angles to the onward course of the storm.

Storms or Hurricanes of the Tropics.

426. In describing the storms of the tropics, the method of description by synchronous charts will be adopted, as in the case of the European storms, in which nothing but observation will be set down.

427. THE BAHAMA HURRICANE OF OCTOBER 1866.*—On Plate V. are exhibited the barometric pressure and the direction of the winds at different places in the West Indies at 8 P.M. on the 1st October 1866, when the centre of the storm was at Nassau. At this instant the barometer was 27.7 inches at Nassau, while at a distance of 300 miles it was as high as 29.7; at Bermuda, St Thomas, and Barbadoes, it was at the average height; but to the east and north-east of Barbadoes it was above the average height of that part of the Atlantic. These figures show such extraordinary fluctuations of the barometer as never occur beyond the tropics. In Great Britain the fall of one-tenth of an inch of barometric pressure in an hour is reckoned a large fall, such as only accompanies great storms; but during this storm, when the barometer was falling most rap-

* The data of this hurricane have been obtained from Commander A. J. Chatfield's Record Chart of the storm, and observations received from Mr Andrew Lang, St Croix, the Royal Mail Steam Packet Company, the Director-General, &c.

idly, it is probable that in one hour it fell an inch and a half.* The fall of the barometer becomes more rapid as the centre of the storm approaches; but at the centre the pressure remains nearly stationary for a time during the lull which there prevails, and before the barometer begins to rise. Since at Nassau the lull at the centre lasted from 7.20 P.M. to 8.50, we learn from the rate at which the whole body of the hurricane was carried forward that the calm at the centre covered an area of at least 23 miles across. Since ordinarily, within the tropics, the barometer rises and falls so little that it may be practically regarded as stationary, such enormous changes of the barometer are the more striking; they are so sudden that the eye, in looking at the mercurial column, can plainly see it falling, and they can but be regarded as registering rather than foretelling the different stages in the progress of the storm.

428. *Storm-Wave of the Sea accompanying the Hurricane.*—Owing to the diminished pressure of the air at the centre of the storm as compared with what prevailed at the outskirts of the storm, the difference being fully two inches of mercury, the level of the sea at the centre would rise about three feet, being sustained at that height by the greater pressure all round. This increase of level, when occurring at high tide and increased still further by the violence of the wind, quite accounts for the advances made by the sea over the land, especially over the low-lying islands, and the heartrending scenes of desolation which occurred in consequence. In certain parts of Turk Islands and some other flat islands, those only were saved from drowning who succeeded in climbing up the trees. The great storm which swept over Calcutta on the 5th October 1864, and which must still be fresh in the memory of all, furnishes a notable illustration of the destructive power of the storm-wave occasioned by such low atmospheric pressures. On that occasion the sea broke through its usual bounds, and laid the whole level country at the mouth of the Ganges under water, by which many thousands of human beings perished.

429. *Direction of the Wind.*—From the chart, Plate V., in which the arrows represent the winds at 8 P.M. of the 1st October, it will be observed that in no instance did the winds blow directly to the centre of least pressure at Nassau, or blow round the area of low pressure in circles returning on themselves; but in every instance

* To show the probable correctness of this estimate, it may be stated that during the hurricane which devastated Guadaloupe on the 6th September 1865, the barometer at Marie Galante, a neighbouring island, was 29.922 inches at 4 A.M., 29.646 at 6.30 A.M., 29.174 at 6.47 A.M., and 27.953 at 7.40 A.M., having thus fallen 1.693 inches in one hour and ten minutes.

they blew in a direction intermediate between these two directions. Hence the storm was rotatory, revolving in a direction contrary to the hands of a watch; and within the area of rotation the winds approached the centre by spirally in-moving currents of air. If the mainspring of a watch, with the successive spirals somewhat apart, was laid down on the chart, having its centre at Nassau, it would represent pretty accurately the path followed by the wind in approaching the centre of the storm. It will be observed that the winds nearest the centre blew more directly towards it than those at a greater distance from it. In this respect this hurricane resembled every European and American storm which I have hitherto examined from actual observations laid down on synchronous charts.

430. *Connection between the Direction of the Wind and the Centre of the Storm.*—Standing back to the wind, the centre lies to the *left hand of the direction in which the wind is blowing at an angle of from* 45° *to* 60°. This holds in all places north of the equator, and it furnishes the rule which must be observed by ships in steering out of the course of the storm. From it is also deduced the rule for predicting the direction of the wind at particular seaports during storms. Thus, suppose at 9 A.M. it be required to know the direction in which the wind will blow in London at 9 P.M., a storm being observed advancing from Ireland towards the east. Information being had through the telegraph of the course the storm is taking, and an inference being drawn from that observed course that at 9 P.M. its centre will be near Liverpool, then at that hour the gale may be expected at London from S.S.W.

431. The only exceptions to the rule, shown by the winds on Plate V., are the winds at St Thomas and St Croix. But it must be considered that the storm had already passed these places; the winds were therefore light, and were now beginning to yield to the influence of the high barometer which prevailed at that time to the east and north-east, as will appear from the table in art. 443.

432. *Probable Track of the Centre of the Storm.*—From observations received, the position of the centre was determined at seven points, which were then connected together by the hacked line on the chart. It will be observed that it began to the north-east of St Thomas, and thence pursued a W.N.W. course, coming round to Nassau; thence its course was to the N.E., passing 150 miles to the north of Bermuda; its course thus assuming the form of a parabolic curve, having Nassau near the apex.

433. *Rate of the Onward Course of the Hurricane, and Velocity of the Wind.*—The rate at which the whole body of the storm travelled was slow as compared with European storms, being only fifteen miles, until it had passed the Bahamas and neared

Bermuda, when it proceeded with the accelerated speed of thirty miles an hour. But this rate gives no idea of the violence of the hurricane, which depends not on the velocity of translation of the whole body of the storm, but on the speed with which the winds whirl round the centre. This, doubtless, rose to a steady velocity of from 80 to 100 miles an hour, and for short intervals to 120 or even 150 miles an hour. This higher velocity was registered during the Guadaloupe hurricane of September 1865. The long black list of wrecks recorded bear testimony only too emphatic to the devouring energy of the hurricane.

434. *Veering of the Wind during the Storm.*—At St Croix, which lies to the south or left-hand side of the storm's track, the veering of the wind, as recorded by Mr Andrew Lang, who has paid much attention to these West Indian hurricanes for the last fifty years, was as follows:—On the morning of 28th September the wind was N.E. (the usual trade-wind); at 4 P.M., N.; on the 29th, at 6 A.M., W.; at 10 A.M., W.S.W.; on the 30th, at 6 A.M., S.; on the 1st, at 6 A.M., S.E. It then turned towards the east, and on the afternoon of the 2d was E.N.E. Observations from other six places, or ships, on the left-hand side of the track of the storm all show that the wind veered in precisely the same way—viz., from N.E. to N., W., S., E. The ship Mexican, whose course during the storm was from 200 to 300 miles north-east of Nassau, recorded the following veerings of the wind:—On 1st October, at 6 A.M., E.; at 6 P.M., E.S.E.; on 2d, at 6 A.M., S.S.E.; at noon, S.; and at midnight, S.S.W.; on the 3d, at 6 A.M., S.W.; at noon, W.S.W.; and at 6 P.M., W. Observations from other five places or ships on the right-hand side of the storm's track show that the wind veered in the same direction—viz., from N.E. to E., S., W., and N. At St Croix the wind veered from N.E. by W. to S.E., and afterwards to E.N.E., or nearly round the compass; but by the ship Mexican the veerings were only from E. by S. to W., or about half the compass. In the former case the place of observation was much nearer the centre of the storm than in the latter case. Generally, the extent through which the wind veers at any place diminishes in proportion to its distance from the centre of the storm when it passes; and at places situated just at the outside of the area swept over by the storm, the veering of the wind is very small. These facts regarding the veering of the wind are a simple consequence of the rotary nature of the storm, and its progressive motion over that part of the earth's surface.

435. I constructed other eight synchronous charts of this storm at different points of its course, and they all agreed in the essential features portrayed on the chart, Plate V. I have also con-

structed similar charts of the storms described by Redfield and Reid, and have not found them to differ in any essential point from the Bahama hurricane of October 1866. All are rotary, showing the wind blowing round and in upon the centre of least atmospheric pressure when the barometric depression at the centre was known; and when not, they were observed blowing round and in upon a centre presumed, from the general direction of the winds, to be that of least pressure. None of those examined showed the winds blowing directly towards the centre of least pressure; though in some instances, when observations were had from points in the immediate neighbourhood of the centre, there was a tendency in the winds to turn further round so as to approximate to the centripetal direction. None of the storms, at any hour at which they were charted, exhibited the winds whirling round the centre in perfect circles, but all were "vorticose," to use Sir John Herschel's expression—that is, they were formed of spirally in-moving currents of air.

436. The West Indian hurricanes occur most frequently from July to October. From Poey's 'Chronological Table of 365 West Indian and North Atlantic Hurricanes, from 1493 to 1855,' we learn that 42 have occurred in July, 96 in August, 80 in September, 69 in October, and the remaining 68 were distributed over the other eight months of the year. The tracks of the more important of these storms are laid down in Dr A. Keith Johnston's splendid 'Physical Atlas.'

Storms of other parts of the World.

437. *Typhoons.*—The name typhoon is applied to the storms which occur at certain seasons in the north of the Indian Ocean and in the Chinese Sea. As regards their circular shape, the sudden barometric changes accompanying them, and the blowing of the winds round and in upon the centre, where the pressure generally falls to 28 inches, and even on rare occasions as low as 27 inches, they entirely resemble the West Indian hurricanes already described. The chief point of difference is in the general direction of their route. Thus the general course of the storms of Hindostan is from Ceylon, thence north-eastward, in a line parallel to the coast, to the mouth of the Ganges, after which they turn to the north-west, and ascend the valley of the Ganges. The typhoons of the Chinese Sea have their origin in the ocean to the east of China, especially about Formosa, Luzon, and the islands immediately to the south. They thence proceed from E.N.E. to

W.S.W.; rarely from E.S.E. to W.N.W.; and scarcely ever from N. to S. or from S. to N. Thus the course generally taken by these typhoons is along the Chinese coast; and hence the coast feels the northern side of the storm, while at a distance out at sea the southern side is experienced. They may occur at any time from May to October; but it is during July, August, and September they are most frequent. The season of the typhoons coincides, therefore, with the annual period of the monsoons. Here, then, are two great atmospheric currents—the S.W. monsoon, prevailing over southern Asia, and the ordinary N.E. trade-wind in the Pacific Ocean to the east—flowing side by side, but in opposite directions. On this account an examination of these storms from observations made in China and on the ocean and islands to the east and south of it would have a considerable interest to meteorologists, since from this peculiarity typhoons are well fitted to test Dové's theory of storms originating from opposing currents of wind.

438. *Storms of the Southern Hemisphere.*—These storms differ from the storms which occur north of the equator only in this circumstance—viz., they rotate round the centre in the direction of the motion of the hands of a watch laid on the map face uppermost. As regards the low barometric pressure which accompanies them, and the spirally in-moving currents of air, they are identical in both hemispheres. The usual track of the hurricanes in the south of the Indian Ocean is first westward, then south-westward towards Madagascar, till after having passed the limits of the south trades and entered the region of the return trades they then bend their course towards the south-east, being in these respects quite analogous to the West Indian hurricanes. In high latitudes the usual course of storms is with the return trade-winds, which in the south temperate zone is from N.W. to S.E. Since the direction of the wind round the storm is with the motion of the hands of a watch, it follows that, back to the wind, the centre of the storm will lie to the right of the wind's direction, and not to the left, as in the northern hemisphere.

General Remarks.

439. On the storm charts given in the works of Reid, Dové, and some other writers, the arrows representing the direction of the wind are invariably drawn as flying round the circular area of the storm in perfect circles returning on themselves. These arrows, it is unnecessary to say, in no case represent any winds

actually observed at any particular hour, but are in every instance representative of a hypothesis in the mind of the writer at the time—viz., a particular rotatory theory of storms. They serve the purpose for which they were intended; for by shifting the circles with the arrows drawn on them over the space passed over by the storm, and comparing it with the observations at each place as it is passed over, it is proved beyond a doubt that all these storms are rotatory. But the kind of the rotation is not proved—that is, it is not proved whether the winds blow round the centre in perfect circles, modified only by the progressive motion of the storm, the ideal of the cyclone, or whether they blow round and in upon the centre. I have examined many, especially tropical storms, by synchronous charts, in the hope of lighting on some one that might illustrate the purely cyclonic behaviour of the winds round the centre, but have not yet found one. On the contrary, every storm examined in Europe, in America, or within the tropics, shows beyond a doubt that storms are vorticose. This, be it noted, is not a mere opinion, but the simple statement of the position of the winds in storms as shown by synchronous charts on which the winds are entered exactly as observed at each place. It is therefore a statement unassailable by argument, and must be accepted as the law in accordance with which the course of the wind in storms is regulated. Professor Taylor, followed by Sir John Herschel, has shown that these characters of storms are the result of the "law of rotation" of the wind as developed by Dové, which takes effect when, owing to local heat, the air over some extensive region rises in a vertical column. This rotatory feature of storms becomes intelligible when the winds are regarded as drawn in upon a centre of low atmospheric pressure along the globular surface of the earth rotating eastwards.*

440. Since storms are formed of spirally in-moving currents of air, it follows that *the fall of the barometer at the centre is not the effect of centrifugal force.* For if this was the cause of the low barometer, the wind would blow round the centre in circles, subject only to a slight modification from the onward motion of the storm,—a state of the winds which in none of the storms examined has been found to exist, not even in those cases when the storm was increasing its area and deepening the depression at the centre. Professor Loomis has shown that any observed velocity

* This view of the spirally in-moving course of the winds in storms has been adopted by the following meteorologists:—Dr Buys Ballot, Utrecht, whose system of forecasting the weather is based on it; Dr Joseph Henry, Secretary of the Smithsonian Institution, America; Dr H. Lloyd, Dublin; Sir John Herschel; William Stevenson; &c.

of the winds round the centre is altogether inadequate, on the principle of centrifugal force, to bring about the low pressure at the centre. Thus, if the wind blows round a circle 300 miles in diameter at the rate of 70 miles an hour, the centrifugal force would only depress the barometer at the centre a little more than 0.02 inch; whereas in the Bahama hurricane the difference of the pressure at that distance from the centre was 2 inches, or 1000 times greater than that due to centrifugal force.

441. *But the spiral rotation instead of the circular rotation of the winds in storms completely alters the whole complexion of the question affecting the theory of storms.* For since it follows from it that enormous quantities of air are constantly being poured all around into the area of the storm, and since, notwithstanding these accessions tending to increase the pressure, observation shows that the pressure is not thereby increased, but on the contrary sometimes diminished, *we are compelled to the conclusion that from a large area within and about the centre of the storm a vast ascending current must arise to the upper regions of the atmosphere.* Now all observation shows that in front of storms the air is warm and moist, and it is there that most of the rain accompanying storms falls. Thus far observation; but may we not go a step further, and say that it is the heat of condensation into rain of the vapour of the warm moist air in front of the storm when it has been drawn up into the higher regions of the atmosphere, which relieves the barometric pressure and thus forms the motive power of the storm? If this be the case, then the onward course of the storm will follow that of the upper current within which the condensation of the vapour into rain takes place,—a conclusion which observation appears at present to point to. The theory is also in accordance with the observation that storms generally contract in area as they traverse a dry climate, and die out when they meet or come against the dry polar current, because under such circumstances less vapour being condensed, less latent heat is given out and the barometric disturbance is consequently diminished.*

* This view of the part played in storms by the heat of condensation was first proposed by Brandes, and since adopted by Espy, Hare, Russell, and some others, as part of the theory of storms. It cannot be doubted that the heat given out in the condensation of vapour into rain must play an important part in storms. We have already seen in art. 76, that wherever a copious rainfall prevails over any considerable portion of the earth's surface, there the mean atmospheric pressure is low. We have stated that Espy entered the barometer on his storm-charts on a defective and misleading principle; and from this he may have been led to maintain that the

442. The part of the track of the West Indian hurricanes after turning to the N.E., is in accordance with this theory; but how account for the first part of their course, which is at right angles to the prevailing trade-winds of that region? The usual place where the vapour brought by the trade-winds is condensed, is the region of calms, where heavy rains and thunderstorms daily occur. But since this condensation takes place simultaneously over a somewhat broad belt of the earth's surface, which for the time is stationary, it follows that the storm is neither rotatory nor progressive, the only effect of the condensation being the flow of the regular trade-winds towards the belt where it takes place. When the condensation is more copious than usual, the effect will be the acceleration of the speed of the trade-winds. This is the most probable explanation of the *harmattan* which occurs at certain seasons on the coast of Africa; it always blows in one direction from the land, and does not increase quite to the violence of a gale, and then dies away. Copious rainfall in the belt of calm opposite that part of Africa, and at some distance, is the probable cause of these winds. Similar in some respects to these are the *tornados* of western Africa, which blow invariably off the land, first with little force, but ultimately they rise to the strength of a heavy gale, and then after an hour, or sometimes two hours, die away. The direction of the wind remains all the time unchanged; and the barometer varies little, if any, during their continuance. They are generally accompanied with rain and thunder, though sometimes they are quite dry winds. They are probably caused by very heavy rains in the region of calms, falling over a limited region and lasting only for a short time.

443. Let us suppose that the atmosphere of the West Indian Islands has from some cause become exceptionally warm and moist, and that, at the same time, a high barometer is interposed between that region and the belt of calms. In such circumstances, as the trade-winds cannot flow towards the belt of calms, the usual provision for draining them of their moisture is taken away, and a rapid accumulation of aqueous vapour, to the north of the high barometer, takes place, ready to burst in any instant in rain and

direction of the wind in storms is centripetal—an assertion which neglects theoretically the influence of the earth's rotation on its axis in changing the direction of the wind, and practically the evidence to the contrary furnished by his own storm-charts. But this is no reason for disregarding that part of the theory which refers to the heat of condensation. The centripetal theory has long been abandoned as impracticable by the Meteorological Department of the United States, and the spirally in-moving course of the winds adopted instead.

storm. This would appear to have been the case before and during the Bahama hurricane of October 1866, Plate V. The following table shows the atmospheric pressure and winds at St Croix, and on board H.M.S. Buzzard, which sailed from Barbadoes on the 26th September for England. St Croix is in N. lat. 17° 44′ 29″ and W. long. 64° 41′, and the mean height of the barometer at sea-level is 30.080 inches.

BAROMETRIC PRESSURE AND WINDS OBSERVED AT ST CROIX, WEST INDIES, AND ON BOARD H.M.S. BUZZARD, FROM 26TH SEPTEMBER TILL 4TH OCTOBER 1866.

ST CROIX.				H.M.S. BUZZARD.					
Day of Month.	Hour.	Barometer.	Wind.	Day of Month.	Hour.	Lat. N.	Long. W.	Barometer.	Wind.
Sept. 26	6 a.m.	29.960	E. by S.	Sept. 26	a.m.	13.20	59.00	30.18	N.N.E.
,,	4 p.m.	29.950	S.E.	,,	a.m.	..	..	30.19	..
27	6 a.m.	29.930	E.	27	p.m.	14.10	57.20	30.10	S.W.
,,	4 p.m.	29.910	E.N.E.	,,	p.m.	..	..	30.08	S.W.
28	6 a.m.	29.860	N.E.	28	a.m.	15.30	56.15	30.10	S.E.
,,	4 p.m.	29.930	N.	,,	p.m.	..	..	30.08	E.S.E.
29	6 a.m.	29.734	W.	29	a.m.	17.24	55.42	30.06	E.N.E.
,,	2 p.m.	29.620	S.W.	,,	p.m.	..	..	30.18	E.N.E.
30	6 a.m.	29.920	S.	30	a.m.	19.21	56.60	30.27	E.N.E.
,,	4 p.m.	29.970	S.	,,	p.m.	..	..	30.26	E.N.E.
Oct. 1	6 a.m.	29.990	S.E.	Oct. 1	a.m.	21.50	56.50	30.24	E.N.E.
2	6 a.m.	29.960	E.	2	a.m.	22.55	57.35	30.17	E.N.E.
3	6 a.m.	29.930	E.S.E.	3	a.m.	24.35	58.15	30.11	E.
4	6 a.m.	29.910	E.S.E.	4	a.m.	25.42	58.70	30.20	S.

From this table we learn that during the hurricane, which in all probability began a little to the north of Barbadoes on the evening of the 26th or morning of the 27th September, the atmospheric pressure was above the average to the S.E. and E. of the region traversed by the storm. This being the case, the air would naturally flow from the high toward the low barometer—that is, a general movement of the atmosphere would set in to the N.W., which was the course pursued by the storm for the first four days, a course at right angles to the usual trade-winds. During this part of its course, the rate at which it travelled was slow, not exceeding fifteen miles an hour. Such a slow, and often a much slower, progressive motion is common to these storms until they enter the region of the return trades, when the course is changed to the N.E., becomes greatly accelerated, and the storm itself expands over a wider area.

444. Newspaper accounts of the weather before the hurricane describe it as close and sultry, the whole atmosphere being ab-

normally heated and excessively loaded with moisture. At Bermuda, at 9 A.M. of the 4th October, the temperature of the air was 79°.4, and the dew-point 73°.6, the humidity, therefore, being 83: and this kind of weather had been prevailing for fully a week before. On the following day, the 5th, at 9 A.M., when the storm had just passed, the temperature was only 71°, the dew-point 56°, and the humidity 59°. Next night the temperature fell to 56°, whereas, before the storm, it did not fall on any night lower than 72°. It would be interesting to know if West Indian hurricanes occur simultaneously with a high pressure to the south, being thus interposed between that region and the usual position of the belt of calms at that season. If so, a considerable step will be gained toward understanding the causes of their origin, and how it is that they are, happily, phenomena of very rare occurrence. The barometric pressure in the south-eastern States of America would have possessed peculiar interest; for if the pressure had been low there, it would have still further accounted for the course of the hurricane to the N.W. But the meteorological observations, which had been discontinued there during the war, had not then been resumed.

445. Perhaps no writer in meteorology denies the influence of low pressures in drawing the winds toward them; but the effect of this influence in accounting for the rotation of storms round their centres is in general tacitly subordinated to a theory by which the storm is conceived to rotate from some force quite distinct from that arising from differences of pressure, and in virtue of this rotation the air to be driven to the outside of the whirl, thus diminishing the pressure at the centre; much in the same way as, in whirling round a pail of water, part of the water leaves the centre and rises up against the sides of the vessel. In applying this theory to cyclones, the wind at every point within the storm is stated to be under the influence of two forces, the one arising from the rotatory motion of the cyclone, and the other from its progressive motion. To illustrate this by an example:— Suppose a storm advancing over England to the eastward at the rate of twenty-five miles an hour, and taking the simplest case of the wind whirling round within the storm at the rate also of twenty-five miles an hour, then both the rotatory motion of the winds and the progressive motion of the storm are from the west, at the extreme south point of the storm; hence there the wind ought to be due west. At the extreme east point of the storm, since the direction of the wind due to the rotatory motion is south, and by the progressive motion west, the wind ought to be seen blowing there from the south-west. At the extreme north,

since the rotatory motion is east, and the progressive west, and both equal, there should be no wind at all. Lastly, at the extreme west point of the storm, the rotatory motion being north, and the progressive west, the wind should be north-west. Further, since in the south half of the storm the direction of the two motions is generally the same, and in the north half generally opposite, the gale ought to be most severely felt in the southern half of the cyclone, attaining its height at places immediately south of the centre, and least in the northern half. When the rotatory motion much exceeds the progressive, the deviations from the true circular course of the winds when laid down on a synchronous chart would be less than those stated above; but in all cases, unless when the cyclone was stationary, the winds in the front part of the storm ought to be observed blowing *out of the circular area of the storm.* I am altogether at a loss to discover a storm to which this theory applies. If we look at the West Indian cyclone of October 1866, Plate V., we do not see any of the winds observed at 8 P.M. show even a tendency to blow in a direction in accordance with the theory, but, on the contrary, they all blow round and in upon the centre. To the European storm of the 2d November 1863, Plate IV., the same remark applies, as well as to every storm in tropical and temperate regions which I have examined on synchronous charts. The light winds which often prevail in the northern half of European storms are sometimes referred to in illustration of this theory; in such cases it will be found, on examination, that there the isobarometric lines are considerably apart (see art. 419). But when it happens that the isobarometric lines are much crowded together on this side of the storm, the winds are strong and violent. The parts of a storm where probably the winds are not generally proportioned to the difference of pressure, are, that part of the front where the ascending current is strongest, thus diminishing the force of the surface-current, and that part of the rear where the air is coldest and driest, and, as the clouds often show, descending currents prevail.

446. It should be kept in mind that this theory was not arrived at through the slow and tedious process of a rigid induction—viz., by collecting the observations of the barometer and winds on synchronous charts, from which, their mutual relations having been observed, a theory was then constructed in strict accordance with the facts; but from observations, necessarily at the time few and scattered, it was inferred that the rotation of storms is circular, and this inference necessitated another—viz., that the rotation is caused by some force or forces acting on the storm from without.

Hence the theory proposed by the illustrious Dové, that *storms are produced by the mutual lateral interference of two currents of air flowing in opposite directions.* It is very difficult to imagine how the polar and equatorial currents could be brought to affect each other as they flow in opposite directions, so that between them an atmospheric eddy or whirl 1200 miles in diameter could be formed rotating round its axis at the rate of 50 or 70 miles an hour. That storms often occur between these two great currents is undoubted; for in such cases the dry, heavy polar current, by flowing under the moist, warm equatorial current, and thus thrusting it into the higher regions of the air, produces that disturbance in the atmospheric equilibrium which constitutes a storm. But what is maintained by the theory is this: By the lateral interference of these two currents, combined with the change in their direction produced by the rotation of the earth, a storm is formed. In support of this theory, the great storm which occurred in the beginning of January 1855 is adduced. I have examined Dové's account of that storm,* and, from the Russian Observations, Dr B. Ballot's Jaarboek, and other sources, prepared eight synchronous charts of the weather of Europe from the 27th December 1854 to the 3d January 1855. From these charts we learn the following facts regarding this singular storm:—1. It was for some time preceded by southerly winds, high temperatures, and low pressures over the north and north-west of Europe. 2. It originated in some locality within the arctic regions unknown. 3. It thence advanced over the Lofoden Islands, Stockholm, and Konigsberg, to the Sea of Azov, its direction being thus from N.W. to S.E. 4. A high barometer prevailed to the west and south-west of its course, and another region of high barometer in eastern Russia and Siberia; these approached towards each other till the 29th December, after which they both fell back or gave way to the storm as it passed between them to the S.E. 5. The storm reached its greatest development on New Year's Day at noon, when its centre was near Christiania, after which, as it proceeded on its course, its area became more contracted, and the depression at the centre became less. 6. In north Germany and Denmark, to the right of the storm's track, the wind veered from S.W., by W. and N.W., to N.; and at Riga, St Petersburg, and other places to the east or left-hand side, it veered from S.E., by E. and N.E., to N.—these directions being in accordance with the law of the veering of the wind in storms. 7. In every one of the charts the wind is seen blowing from the high to the low barometer, the direction being modified only by

* See 'Law of Storms,' p. 258 *et seq.* London, 1862.

the change produced by the rotation of the earth; no other movement of the wind is observable than the spirally in-moving currents of air towards the area of least pressure. 8. On the 1st January, the pressure at Christiania being 28.30 inches, and at Greenwich, only 700 miles distant, 29.96 inches, a furious nor'-wester of unexampled violence descended over the North Sea on the north coasts of Germany and the Netherlands, and washed away part of the island Wangeroog.

447. From a high barometer on the 1st in the west of Europe and east of the United States, and a low barometer and storm in California, Dové infers a barometric maximum extending over the whole Atlantic, and that the storm in Europe on the one hand, and the storm in the west of America on the other, were produced by the lateral interference of equatorial currents with the polar current which was between them; and attention is drawn to the circumstance that the Californian storm came from the S.W. and the European from the N.W. It will be observed that the only observations from which a high barometer is assumed for the whole of the Atlantic are the barometers on its eastern and western shores. From Professor Alexis Caswell's observations at Providence, Rhode Island, America, it is seen that a heavy storm passed over that place to the east on the 29th December, during which the barometer fell to 29.41, after which the wind veered from W. to N.W., the barometer rose, and the temperature fell. A storm from the west passed over Scotland on the 4th of January, and reached St Petersburg on the 6th. We need not here stop to inquire if these were one and the same storm, but only to remark that their occurrence throws doubt on the supposition that the whole of the Atlantic was at this time under a maximum barometric pressure. The facts of the storms of the 1st and 2d January 1855 do not, so far as I can see, offer any support to the theory of the simple mutual interference of currents generating storms. No attempt should be made to discuss the weather-conditions of so large a portion of the earth's surface as North America, the North Atlantic, and Europe, until a sufficient number of observations have been procured, so that the isobarometric lines may be laid down over the whole space with some tolerable approach to accuracy.

448. An examination of weather-changes over large portions of the surface of the globe from day to day, leaves a deep and lasting conviction on the mind of the essential unity of the earth's atmosphere, and, *a fortiori*, the oneness of comparatively so small a portion as that of Europe, in respect of the intimate relations of

its different parts, and their absolute dependence on each other. We have seen waves of temperature creeping over that continent, apparently so vast that only a mere fragment of one of them could be exhibited by the whole continent at one time; and the same remark applies with equal force to the waves of barometric pressure which pass across it. Let the pressure in the north of Europe be diminished, then the winds over the whole continent become southerly, accompanied with a general rise in the temperature; let the pressure in the north be high, and in the south low, northerly currents and low temperatures will prevail; let the pressure in the west be generally low, but high in the east, then easterly winds will prevail, and the temperature will rise or fall according to the season; let the pressure in the east be diminished, then westerly winds will prevail; and, finally, let the pressure be low over some contracted space such as England, then winds will flow in upon it from every side, giving rise to an extensive whirl in the atmosphere over that region, as the winds turn round and in upon the centre of least pressure.

449. But of the causes of these vast atmospheric changes we are profoundly ignorant. The general prevalence of the polar and equatorial currents may be, perhaps, satisfactorily reasoned about; but why on any particular day the polar current does descend from the frozen regions, and spread itself over Europe, and why at another time the equatorial current flows wholly or partially over that continent, the area of our observations is too contracted to show. Meteorology is eminently the science of observation and averages, and before those inquiries now raised regarding the general movements of the atmosphere can be satisfactorily and adequately discussed, it is indispensable that the field of observation be extended, so as to embrace nearly the whole of the northern hemisphere.

450. The present state of our knowledge of the science may be thus put:—Given in any locality an excess or diminution of atmospheric pressure, an excess or diminution of atmospheric temperature, and an excess or diminution of atmospheric moisture, we know the atmospheric changes which will take place in the effort to restore the equilibrium thus disturbed, and can to some extent turn this knowledge to account in predicting the weather. But as regards the specific conditions out of which those great atmospheric disturbances take their origin, we really know nothing; and it is to acquire this all-important knowledge that we urge the extension of the field of observation, so that synchronous charts of the northern hemisphere might be constructed, which would supply the information desiderated.

CHAPTER XI.

MISCELLANEOUS.

Atmospheric Electricity.

451. THE identity of lightning and electricity was first suspected by Wall in 1708, but it was reserved to Franklin to prove it. In 1749, he suggested, as the mode of proof, the erection of pointed metallic conductors properly insulated. Acting on this suggestion, Dalibard erected near Paris a pointed iron rod, 40 feet in length, and insulated; and on the 10th of May 1752 obtained electrical sparks from it. In June, Franklin, impatient at the delay in erecting the spire on which to place his pointed conductor, conceived the happy idea of drawing electricity from the clouds by flying a kite. The kite was flown with a hempen string, to the lower end of which a key was attached; and the whole was insulated by tying a silk ribbon to the key, the other end of the ribbon being attached to a post. On the approach of the thunder-cloud, he raised the kite, and soon the fibres of the hempen string began to erect themselves and repel each other; and at last, when the rain had moistened the string, he had the intense satisfaction of drawing electrical sparks from the key. The experiment was repeated by Romas during a thunderstorm in France, in June 1853. Instead of a string, he used fine wire (550 feet long), and obtained flashes of electrical fire, 9 or 10 feet long, and an inch in thickness, which were accompanied with a loud report. Thirty of these were obtained in one hour. In August of the same year, Professor Richmann of St Petersburg lost his life when engaged in similar experiments.

452. *Electrometers* are instruments used for indicating the electricity present in the atmosphere. A pole is erected in an open situation on a rising ground, having an insulated pointed metallic wire on the top, to which an insulated wire is attached for conveying the electricity to the electrometer in the place of observa-

tion. Fig. 44 represents Bennet's *gold-leaf electrometer*, which consists of a glass jar with a metallic cap, in the centre of which a wooden wedge is inserted. On each side of it a thin strip of gold-leaf, two inches long, is attached, and opposite each, tinfoil is pasted within the jar, rising a little above the lower edge of the gold-leaf, and connected below with the brass stand of the instrument. A pointed wire rests on the cap in connection with the gold-leaf. When this pointed wire receives electricity, the gold-leaves diverge, and by the degree of divergence, measured on a graduated arc, the intensity of the electricity is ascertained. A condenser is used when the electric tension is too feeble to cause the gold-leaves to diverge. In Volta's electrometer, two thin blades of straw are used instead of the gold-leaf, and in Cavallo's two pith-balls.

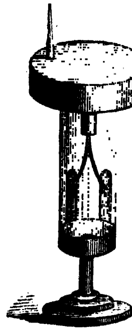


Fig. 44.

In Henley's *quadrant electrometer*, fig. 45, a semicircle of ivory is fixed upon a rod rising from a stand, from the centre of which a pith-ball is hung by a piece of slender cane; and the elevation of this ball indicates the quantity of the electricity.

453. *Electroscopes* show whether the electricity is positive or negative. In Bohnenberger's electroscope, a gold-leaf is suspended between the poles of two "dry piles," charged with the opposite electricities; when, therefore, an electric body is brought into contact with the knob, the kind of electricity is known by the gold-leaf being attached to the opposite electricity.

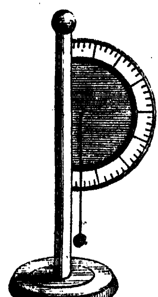


Fig. 45.

454. The electricity of the atmosphere is almost invariably positive. At Kew Observatory, during the years 1845-6-7, of the 10,500 observations, 10,176 were positive, and only 364 negative. The negative observations almost all occurred during heavy rain. In relation to the air the earth's surface is always negative.

455. The electricity of the air increases in intensity with the height. This was shown by an ingenious experiment made at the Great St Bernard, by Becquerel and Breschet. A silk cord, with a fine wire twisted into it, was attached to an electrometer at one end, and an iron arrow tied to the other, and was shot from a bow to the height of 250 feet. As the arrow ascended, the thin straws of the electrometer separated more and more, and at

last struck against the sides of the jar. The arrow was then shot horizontally, but no increase of the electric tension was observed. This conclusion has been confirmed by flying paper kites, and sending up captive balloons into the air.

456. The electricity of the atmosphere is stronger in winter than in summer, increasing from June to January, and decreasing from January to June. It is subject to a double maximum and minimum each day. Saussure and Schübler have shown that the first maximum occurs from 6 to 7 A.M. in summer, and from 10 A.M. to noon in winter; it then falls slightly to the first minimum between 5 and 6 P.M. in summer, and between 2 and 3 P.M. in winter, or shortly after the period of the maximum temperature; it rises to a second maximum a little after sunset, and then increases to a second minimum, which is reached about daybreak.

457. *Sources of Atmospheric Electricity.*—1. *Evaporation.*—Electricity is produced when *impure* water is evaporating, or water in which some degree of chemical décomposition takes place, none whatever being produced by the evaporation of pure water. Evaporation from water containing alkaline solutions gives off negative electricity to the air, and leaves positive electricity behind; but when the water contains saline solutions, positive electricity is given off, and negative is left behind. Hence seas, lakes, and rivers are abundant sources of electricity, particularly of the positive sort. 2. *Vegetation.*—The vegetable kingdom is also a source of electricity, (1) from the evaporation going on by which water is separated from the sap of the plants, and (2) from the giving off of oxygen gas during the day, and carbonic gas during the night. In these cases positive electricity arises from the plants, and negative is left behind. 3. *Combustion.*—During the process of burning, bodies give off positive electricity, and become themselves negatively electrified. This is frequently seen on a grand scale during volcanic eruptions. 4. *Friction.*—Wind, by the friction it produces upon terrestrial objects, and by the friction of the particles of dust it carries with it, contributes to the electricity of the air.

458. *Effect of the Condensation of Vapour.*—The following are Sir John Herschel's views on the relations subsisting between the condensation of vapour and atmospheric electricity. When a great multitude of the ultimate molecules of vapour are condensed by cold into a drop or snow-spangle, however minute, that drop collects and retains on its surface the whole electricity of the molecules from which it is formed. Suppose a number, say 1000, of such globules to coalesce into one, the electric contents,

being the sum of those of the elementary globules, will be increased one thousandfold, and, being spread entirely over the surface, will have a tenfold density or tension. This view explains the amount of electricity observed in the lower stratum of air when dew is being deposited, and the highly electrical state of fogs and clouds. It also explains the annual fluctuation; for since in winter the condensation of vapour is greater and occurs with greater frequency than in summer, the average quantity of electricity, as observed, will be greater in winter than in summer. At this season, also, the south-west winds acquire their greatest frequency. The daily fluctuation is similarly explained. When the sun has risen, and from the increasing temperature evaporation is most active, the first maximum period of electricity occurs; but when the air, becoming still warmer, is able to hold its vapour in solution, and evaporation has become feebler, the electricity decreases. Again, after sunset, when dew is most copiously deposited, the second maximum period is attained; and, lastly, toward sunrise, when little dew is deposited, and evaporation is also small, the second and chief minimum period occurs. But great difference of opinion exists in regard to the electricity of the atmosphere, and many of the phenomena observed, especially during storms, are difficult to explain.

Thunderstorms.

459. The thunderstorm is originated in the same manner as cloud and rain—viz., by the condensation of vapour; but it differs in the condensation being more copious and more rapid, so as to bring about an accumulation of a sufficient quantity of electricity. If the condensation be not copious, the electricity will be too weak; and if not sudden, it escapes before collecting in sufficient quantity for a discharge. Hence each flash of lightning is immediately followed by a heavy fall of rain or hail, which began to fall simultaneously with the electric discharge.

460. Thunderstorms occur most frequently within the tropics, and diminish in frequency towards the poles They are also more frequent in summer than in winter; during day than during night; after midday than before it; and in mountainous countries than in plains. Within the tropics they prevail most in the region of calms and during the rainy season; and least in arid deserts and during the dry season. Before the storm bursts, the air is felt to be exceptionally warm and stifling, and peculiarly so when the storm occurs in winter or during night; and after it

has passed, the temperature falls generally to a very marked extent. Thunder and lightning often accompany whirlwinds. In all these cases it will be observed that when thunderstorms occur, the required conditions are present, *abundance of aqueous vapour, and a degree of cold sufficient to bring about rapid and copious condensation.* During thunderstorms sudden changes from positive to negative electricity, and *vice versa*, take place. The negative state is probably induced by the friction of the rain-drops on the air as they fall through it, Faraday having shown that the friction of drops of pure water develops negative electricity in the substance rubbed; and the positive state is a return to the normal condition after the action of the rain-drops has ceased.

461. From this it follows that electricity is not *the cause but one of the effects* of violent storms of rain and hail; or to speak more correctly, the electrical manifestations and the rain are both the immediate results which follow rapid and copious condensation of vapour. Electricity cannot be regarded as the agent concerned in producing rain, hail, whirlwinds, or storms,—long a cherished belief with many.

462. *Lightning.* — Arago has divided lightning into three kinds—viz., zigzag-lightning, sheet-lightning, and ball-lightning. When the electric flash speeds through the air, it takes the path of least resistance; and since the conducting power of different portions of the atmosphere is unequal, the lightning appears *zigzag.* When branches are given off at different points of its course, the lightning is said to be forked. *Sheet-lightning* is the most common, appearing as a glow of light illuminating the sky. The flashes often follow each other in quick succession, and the thunder which accompanies them is low and at a considerable distance. Analogous to this is *silent-lightning*, frequently termed *heat-lightning*, which generally occurs during serene summer evenings, lighting up the sky fitfully for hours, with repeated faint flashes; it is not attended with thunder. It is probable that this kind of lightning is almost always the reflection of the lightning of distant storms from the vapour of the upper regions of the atmosphere, the storms themselves being so far off that their thunder cannot be heard. In Scotland, silent-lightning is a prognostic of unsettled weather, it being considered as heralding a storm which is coming up. *Ball-lightning* is the least common. It appears as a globular mass, moving slowly or sometimes remaining stationary, and in a short time explodes with violence. It has not yet been satisfactorily explained.

463. *Thunder* is probably the noise produced by the instantaneous rushing of the air in filling up the vacuum left by the light-

ning along the path of the discharge. The crackling sound of flames is a familiar illustration of a similar phenomenon. Flashes of lightning frequently extend two or three miles in length; and since the thunder is produced at every point along its course nearly at the same instant, the prolonged rolling noise of thunder arises from the different intervals of time it takes the sound to reach the ear. For since sound travels at the rate of 1118 feet per second, it is first heard from the nearest point of the flash, later and later from points more distant, and the combined effect is a continued peal of thunder. The direction of the peal and its character will depend on the length of the flash, and the greater or less obliquity of its course as regards the observer. Reverberations from clouds and from mountains frequently heighten the effect and prolong the peal. From the rate at which sound travels, if the thunder is not heard till five seconds after the flash, the distance is about a mile. Thunder has not been heard at a greater distance than 14 miles from the flash.

464. Thunderstorms are generally very local; however, they sometimes extend over a wide district. On the 11th January 1815 a thunderstorm stretched from Antwerp to Minden, or about 200 miles, and from Bonn to Nimeguen, or nearly 75 miles. When the May monsoon of 1848 burst upon India, it was accompanied with a thunderstorm which covered a district 600 miles from north to south, and 50 miles in breadth.

465. The great proportion of electrical discharges pass into the air, or into other clouds less highly electrified; a very few only take place between the cloud and the earth. The destructive effects of this latter class are known to all. By the electric discharge innumerable lives have been destroyed, the strongest trees rent to pieces, heavy bodies displaced, iron and steel magnetised, metals and rocks softened and fused, and combustible substances set on fire. Sir John Herschel mentions a remarkable instance of "a large oak-tree near Alton, Hants, which was rent into ribands, and every limb of which had been struck off as if by an axe, and had fallen around the tree as by mere privation of support, without lateral projection." He adds: "In producing these effects, the electricity would seem to act immediately by the expansion of vapour generated by its violent heat." When the thunderbolt falls upon sand it occasionally produces *fulgurites* or *fulminary tubes*, being siliceous tubes of various sizes vitrified internally.

466. *Lightning-Rods.*—The lightning-rod was introduced by Franklin as a means of protecting buildings from the destructive effects of electricity. The advantage gained by it consists not in protecting the building in case of a discharge by allowing a free

passage for the electric fluid to escape to the earth, for it is but a poor protection in such a case; but in quietly and gradually keeping up the communication, it tends to maintain the electric equilibrium, and thus prevent the occurrence of a discharge. The best are made of copper not less than three-quarters of an inch thick, and pointed at the upper extremity. They should be of one piece throughout, securely fastened to the building, and joined by strips of metal to any metallic gas or water pipes that may be about the building. The lower extremity should part into two or three branches bent away from the house, and carried sufficiently far into the soil so as to meet water or permanently moist earth.

467. *St Elmo's Fire.*—This meteor is the *Castor and Pollux* of the ancients, and is frequently mentioned in classic writings from the Argonautic expedition downwards. Cæsar notices its appearance after a storm of hail in these words: "Eâdem nocte legionis quintæ cacumina suâ sponte arserunt." The finest and most beautiful displays of this most striking phenomenon occur at sea during storms, when it appears as a light resting on the masts. Mr W. Trail of Orkney gives a particular description of it as seen by him there during a storm in 1837. The mast was illuminated, and from the iron spike at the top a flame a foot in length pointed to a dense cloud from N.N.W. rapidly advancing. As the cloud, accompanied with thunder and hail, approached, the flame increased, following the course of the cloud, till it reached 3 feet in length, when the cloud was passing overhead; after which it quickly diminished, still pointing to the cloud as it was borne to the S.S.E. It lasted about four minutes.

468. If in a dark room we bring a needle close to the conductor of an electric machine when charged, a light will be seen to play on the point of the needle caused by the passing of electricity from the conductor to the needle. This simple experiment explains St Elmo's fire, which takes place when electrified clouds approach near the earth, and the electricity, though intense, does not escape in flashes of lightning, but from different points which appear to glow with a bright flame.

469. Hailstorms.—The hailstorm is one of the modifications of the thunderstorm. Since they occur where the force of thunderstorms is most concentrated, they are of a more local character, and their occurrence and destructiveness would appear to be to a large extent determined by the configuration and vegetable covering of the earth's surface. They seldom occur during the night or during winter; but most frequently in summer, and during the hottest part of the day. They are most frequent within the tropics, less so in temperate climates, unless in the vicinity of mountains, and

still less in the arctic regions. They are more common in the vicinity of mountains than in plains; thus the south of France, lying between the Alps and the Pyrenees, suffers much from hailstorms, the vines being often broken and destroyed by their violence. The annual loss from this cause has been estimated at above two millions sterling. So important is a proper knowledge of these and similar storms considered in France, that the services of upwards of 1200 observers have been secured in that country to note the chief features of storms. The observations are transmitted to the Imperial Observatory at Paris, and the results are published annually in a magnificent atlas of storm-charts. The following storm is one of the most remarkable.

470. On the 7th May 1865 the north-east of France was visited by a hailstorm of unwonted violence, which has since been called the *Storm of Câtelet,* the place where it was most severe. It was preceded by six weeks of unusually dry and warm weather; after which, and a few days before the storm, the temperature became quite scorching, and several times storms appeared to be forming, but they all passed off without hail or rain. At seven in the morning of the 7th the air freshened and the barometer rose. A wind from N.E. chased light clouds before it with astonishing speed; but higher up a S.W. wind prevailed, bearing slowly before it woolly-looking clouds, which grew denser towards noon. Still the air was calm at the surface of the earth, and continued so till three P.M., when dense heavy clouds, piled on each other, rose out of the south-west, and thunder began to be heard. Below, the mass of cloud was of a pale livid colour, from which lightning darted continually; above were many layers or banks of sombre-tinted clouds, forming a broad base to the lower electrically-charged cloud, which resembled an inverted pyramid. The storm ascended the valley of the Somme, but little damage was done till it had crossed the heights and descended into the valley of the Escaut, where it fell with terrible violence on Vend'huile, le Câtelet, and Beaurevoir. At Câtelet the hailstones were as large as pigeon's eggs, and some even as large as hen's eggs; but these latter, on examination, were found to be composed of several hailstones rolled together. Next morning, at one place the hail had piled up a mass of ice which was upwards of a quarter of a mile in length, 22 yards in breadth, and at certain points above 16 feet in height; and at another place there was a similar mass of hailstones one mile and a quarter in length, and a furlong in breadth, which was not fully melted till after the 13th of the month. The damage done by this storm was immense—the tiles on the roofs of houses, the

glass, and even the sashes of windows, were smashed to pieces; a mill was levelled with the ground; large trees were torn up by the roots; and crops of rye, barley, and wheat were beaten to the ground and destroyed. In the memory of man no storm had occurred fraught with so disastrous results.

471. On the 28th July 1818 a hailstorm passed over Orkney, its course being marked for twenty miles, the breadth being only a mile and a half. It did not last longer at any place than nine minutes, during which 9 inches of ice fell. On the 13th July 1788 a hailstorm passed directly from the south-west of France to Utrecht. It moved in two parallel columns with the greatest rapidity, traversing the distance in less than nine hours. The length of the one was 435 miles, and of the other 497 miles, and the breadth respectively 5 and 10 miles. Between the two tracts there was a space of twelve miles, where no hail, but heavy rain, fell. At each place the storm lasted only a few minutes; and along its course property valued at above a million sterling was destroyed.

472. This class of storms are found in France to be invariably bound up or associated with barometric depressions, and their general direction is influenced as is that of the wind in the same circumstances. The general direction in which they advanced in 1865 was from S.W. to N.E.; and otherwise on this point they resembled the storms of Europe already described. But when they were confined to the lower parts of the atmosphere they were diverted from their course on coming up against high table-lands and mountain-ranges much in the same way apparently as rivers are when high banks oppose their course. The rate of their progressive motion varied from 12 to 45 miles an hour, thus showing in this respect also a close correspondence with the larger storms of Europe.

473. In rainy weather, such as frequently occurs in March and September, when, between the intervals of sunshine, a cloud appears in the west, overspreads the sky, and as it passes pours down a considerable quantity of rain, if the barometer be watched from the time of the cloud's appearance in the west to its disappearance in the east, it will be observed to fall a little and then rise, the fall being of a strictly local character. This may be considered typical of the class of storms under discussion. Though no barometric observations are recorded during the thunderstorms of France in 1865, it is highly probable that a local barometric depression accompanied the storm in its course. In all cases before the storm the air is close and sultry and highly charged with moisture. These storms may thus be regarded as secondary storms

or sub-storms within the area of the more general storm passing over Europe at the time, with the wind in all probability circling round them as they are carried forward in the larger storm. Barometric and wind observations made almost every minute during thunderstorms would go far to explain their true character.

Whirlwinds and Waterspouts or Trombes.

474. Whirlwinds are in several respects very different from the storms already described. They seldom last longer than a minute, sometimes only a few seconds; their breadth varies from 20 to a few hundred yards; their course seldom exceeds 25 miles in length; and while they last, the changes of the wind are sudden and violent. The direction of the eddy of the whirlwind, especially when of small diameter, differs from the rotation of the winds in a storm, in that it may be either way according to the direction of the stronger of the two winds which give rise to it. Thus, suppose a

Fig. 46.

whirlwind produced by the brusling of a north with a south wind, then if the north wind be the stronger, and on the west, the whirl

will be in the direction of the hands of a watch, but if the south wind be the stronger the eddy will turn in the opposite direction.

475. Whirlwinds from a different cause are often originated in the tropics during the hot season; especially in flat sandy deserts, which, becoming unequally heated by the sun, give rise to numerous ascending columns of air. In their contact with each other, these ascending currents give rise to eddies, thus producing whirlwinds which carry up with them clouds of dust. Of this description are the *dust-whirlwinds* of India, which have been described and profusely illustrated by P. F. B. Baddeley. Figs. 46 and 47 represent two of these remarkable phenomena. The large arrows in fig. 46 show the rotation of the whole whirlwind round its axis, while the small arrows show the rotation of each column round its own axis. Fig. 47 shows the general appear-

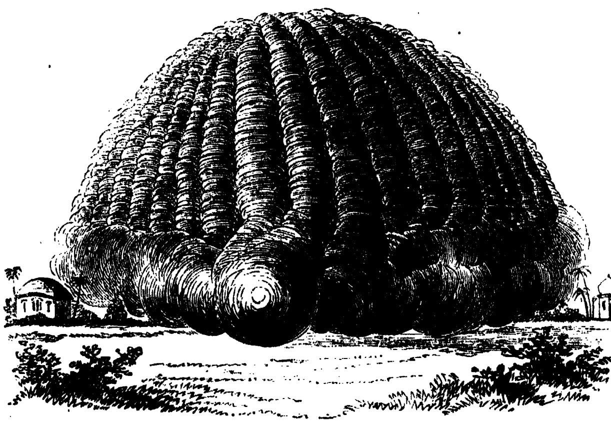


Fig. 47.

ance of these dust-whirlwinds viewed at a distance. A dust-storm is occasioned by a number of whirlwind columns moving together over the earth's surface. The storm generally comes on without warning from any direction, and the barometer is not perceptibly affected by it. A low bank of dark cloud is seen in the horizon, which rapidly increases, and before the spectator is aware the storm bursts upon him, wrapping everything in midnight darkness. An enormous quantity of dust is whirled aloft, which is sometimes broken into distinct columns, each whirling on its axis.

Violent gusts or squalls succeed each other at intervals, which gradually become weaker, and at the close of the storm a fall of rain generally takes place. The air is often highly electrical from the friction of the dust-loaded currents against each other. The simoom may be regarded as in part a whirlwind or a succession of whirlwinds of this description.

476. Extensive fires, such as the burning of the prairies in America, and volcanic eruptions, also cause whirlwinds by the upward current produced by the heated air; and these, as well as the other whirlwinds already mentioned, are occasionally accompanied with rain and electrical displays.

477. *Waterspouts.*—Waterspouts are whirlwinds occurring over the sea or over sheets of fresh water. When fully formed they appear as tall pillars stretching from the sea upward to the clouds, and exhibiting the same whirling motion round their axis, and the same progressive movement of the mass, as the dust-whirlwinds. As they consist of vortices of wind in rapid motion, the sea is tossed into violent agitation round their bases as they career onwards, the waves being broken up so as to resemble the surface of a glacier or water in rapid ebullition. The danger arising from them consists in the enormous velocity of the wind, and the sudden changes in its direction experienced by ships in passing through them. It is a popular fallacy that the water of the sea is sucked up by them, it being only the spray from the broken waves that is carried up the whirling vortex; this is shown by the fact that the water poured down on the decks of vessels from waterspouts is either wholly fresh, or only slightly brackish.

Aurora Borealis and Terrestrial Magnetism.

478. The aurora borealis is the luminous appearance in the northern sky, which forms, in most vivid displays, spectacles of surpassing beauty. The aurora is observed also in the neighbourhood of the south pole, and is there called aurora australis. From their lively tremulous motion they have been called "the merry dancers." When fully developed, the aurora consists of a dark segment, surmounted by an arch of light, at right angles to the magnetic meridian, from which luminous *streamers* quiver and dart toward the zenith. Several auroral arches are sometimes seen at once. Thus, on one occasion at Bossekop, in Finland, nine arches were visible, separated by dark intervals, and resembling in their arrangement magnificent curtains of light hung behind and below each other, their brilliant folds stretch-

ing completely across the sky. Sometimes the streamers appear to unite near the zenith, forming what is called the *corona* of the aurora, towards which the dipping needle at the time points. The convergence of the rays in this case is only apparent, being merely the effect of perspective.

479. The aurora is of great extent, having been sometimes observed simultaneously in Europe and America; and their height has been estimated variously up to 300 miles above the earth. From observations made on one which appeared in England during March 1826, Dalton calculated its height at 100 miles. Sir John Herschel determined the height of one seen on the 9th March 1861 by himself in Kent, and at the same time by Mr Lowe at Nottingham, to be eighty-three miles. Of auroras which have been seen near the earth, the one thus described by Captain Parry is the most remarkable:—"While Lieutenants Sherer, Ross, and myself were admiring the extreme beauty of the northern lights, we all simultaneously uttered an exclamation of surprise, at seeing a bright ray of aurora shoot suddenly downward from the general mass of light, and between us and the land, which was there distant only three thousand yards. I have no doubt that the ray of light actually passed within that distance of us."

480. The aurora is not often seen in summer, partly, no doubt, on account of the short nights and clear skies. There is, however, a double maximum and minimum occurrence in the year, which the following table from Kaemtz, giving the number of auroras seen in each month, clearly establishes:—

Jan., 229.	April, 312.	July, 87.	Oct., 497.
Feb., 307.	May, 184.	Aug., 217.	Nov., 285.
Mar., 440.	June, 65.	Sept., 405.	Dec., 225.

In addition to this annual period, there would appear to be a secular period comprising a number of years. One of these periods extended from 1707 to 1790, attaining its maximum about 1752. After this a period of twenty years intervened, during which they became rare; but from the year 1820 they have become more numerous.

481. The culminating point of the auroral arch being in the magnetic meridian, and the centre of the corona in the line of the dipping-needle produced, *point out an evident connection between the aurora and terrestrial magnetism.* The magnetic needle is also much agitated during aurora. When the arch is motionless, so is the needle; but as soon as streamers are shot out, its declination changes every moment, and this happens though the

aurora does not appear in these latitudes, but is seen near the pole. According to Hansteen, the intensity increases greatly a short time before the appearance of the aurora; but as soon as the aurora begins, it diminishes in proportion to the brilliancy of the display; and it then returns slowly, generally in twenty-four hours, to its original value. During 1857 and 1858, Captain M'Clintock, when in the arctic regions, observed that the aurora in all cases appeared to come from the surface of open water, and not in any case from the fields of ice,—an observation favouring the idea that the aurora is caused by electrical discharges between the earth and air, and that these are interrupted by the fields of non-conducting ice.

482. General Sabine has discovered that the magnetic disturbances of the earth are due to the sun, but not to his heat and light, and are invariably accompanied by the aurora and by electric currents in the surface of the earth. Dr Balfour Stewart considers that auroræ and earth-currents are to be regarded as secondary currents due to small but rapid changes in the earth's magnetism, and that the body of the earth may be likened to the magnetic core of a Ruhmkorff's machine, the lower strata of the air forming an insulator, while the upper and rarer, and therefore electrically-conducting strata, may be likened to the secondary coil; and the sun perhaps likened to the primary current which produces changes in the magnetic state of the core. If this be so, he adds that the energy of the aurora may come from the sun; but this may be considered doubtful, from our ignorance of the way in which the sun affects terrestrial magnetism. R. P. Secchi, Director of the Observatory of the College, Rome, and H. Marié Davy, Chief of the Meteorological Division in the Imperial Observatory, Paris, have for some time given particular attention to magnetic storms, electric disturbances, and auroræ in their relations to the weather and the prediction of storms. Marié Davy states* that the perturbations of the magnetic needle are joined inseparably with one or more of the three following phenomena:—1. General disturbances of the telegraphic lines due to widespread auroræ, which indicate the general movements of the atmosphere in high latitudes and over the Atlantic. 2. Disturbing currents of a more local character occurring over the telegraphic lines some time before the storm appears to which they owe their origin, thus lengthening the distance and time at which the approach of the storm may be perceived. 3. Disturbing currents still more restricted accompanying the electric changes which occur when the storm itself is passing. The cirrus cloud is composed of very

* 'De la Prévision du Temps,' p. 493. Paris, 1866.

minute crystals; it sometimes appears of a texture so delicate as to elude the eyes of all but the most practised observers; and no doubt it occasionally spreads a screen of microscopic crystals in the upper regions of the atmosphere so thin, that no eye can detect it till it is revealed by electric discharges passing through it. This cloud is due to the equatorial current, which deposits in the higher regions of the atmosphere the watery vapour necessary for the electric discharges, the faint light of which, reflected by the small crystals of the cirrus cloud, form the aurora. For the elucidation of the important questions here raised more magnetic observatories are required, so that synchronous magnetic charts might be made for comparison with similar meteorological charts. If this was accomplished, and the relations among these atmospheric elements discovered, the magnetic and electric states of the atmosphere and the aurora might take their place among the most valuable prognostics of the weather.

Ozone.

483. In the year 1848 Schönbein discovered a new chemical principle, to which he gave the name of *ozone* on account of its peculiar smell. Ozone is generally supposed to be oxygen in an allotropic state; that is to say, it is the same substance as oxygen, but in a different form and endowed with different properties. The properties by which ozone is distinguished from oxygen are the following:—It smells strongly and has the flavour of lobsters; readily discharges the colour from litmus paper, oxydises silver, burns ammonia spontaneously, and converts it into nitric acid; burns phosphorated hydrogen immediately with emission of light; decomposes iodide of potassium, setting iodine free, and hydrochloric acid, setting chlorine free; and is a powerful oxydising and chloridising agent. Oxygen may be transformed into ozone by the electric machine; and there can be no doubt that it is constantly being produced by the electricity which is ever present in the atmosphere, and most copiously by lightning during thunderstorms. As the most powerful known disinfectant, it most readily unites with the gases which arise from decaying vegetable and animal matter, and, by depriving them of their noxious qualities, is a great purifier of the air. It is this property which brings it within the province of the meteorologist, and accordingly it has been extensively observed of late years in Great Britain and on the Continent.

484. Dr Moffat of Hawarden has made some interesting obser-

vations on the connection between ozone periods and the changes of the weather and the prevalence of certain diseases. From the observations he has made, he concludes that when ozone is largely present in the air it is accompanied with diminished atmospheric pressure, increasing temperature and humidity, and the prevalence of the south-west or equatorial winds; and when it is in small quantities the pressure is increasing, the temperature and humidity decreasing, and the north-east or polar winds prevailing. There is a remarkable coincidence between the ozone periods and storm telegrams. Also when any marked increase takes place in the ozone of the atmosphere it is accompanied with diseases of the nervous, muscular, and vascular systems.

485. *Ozonometer.*—The following is the mode of preparing ozone test-papers. Take 200 parts of water, 10 of starch, and 1 of iodide of potassium, and boil together for a few seconds; dip bibulous paper into the solution, and after it is dried, cut it into strips. In observing with it, it is only necessary that a strip be placed in an airy situation, free from wet and the sun's rays. The best position is to attach it to a hook on the inside roof of the box for thermometers (see page 36). After hanging for twelve hours it is taken off and dipped in water. The depth of the blue tint of the paper determines the amount of the ozone, and it is compared with a scale showing the different tints marked according to depth from 0 to 10. The tests generally used are Schönbein's and Moffat's. Care should be taken to estimate the force of the wind during the time, since, in a windy day, more ozone is collected, not because there is more in the atmosphere at the time, but because more air has passed over the tests, thus deepening the tint of the paper. Ozone is more abundant on the sea-coast than inland; in the west than in the east of Great Britain; in elevated than in low situations; with south-west than with north-east winds; in the country than in towns; and on the windward than on the leeward side of towns. It thus appears that it is most abundant where electricity is produced, or is found present in greatest abundance; and least so, or entirely wanting, where electricity is in least quantity, and where there is much decaying vegetable and animal matter.

Optical Phenomena.

486. Though rainbows, halos, and other optical phenomena furnish many most beautiful and surprising spectacles, yet from the very subordinate position they hold among meteorological objects, any description to be given here will be brief and of a popu-

lar character. For a full account of them we must refer to the common treatises on *optics*, to which science they more immediately belong.

487. *The Rainbow.*—The rainbow generally consists of two arches, the inner or primary bow, and the outer or secondary bow, each composed of the seven prismatic colours, violet, indigo, blue, green, yellow, orange, and red; or rather of the three primary colours, blue, yellow, and red, blended together. In the primary bow the violet colour is on the inner side of the bow, and the red on the outer; but in the secondary bow the arrangement of the colours is reversed. Coloured bows are also sometimes seen in the interior of the primary bow, and more rarely at the exterior of the secondary bow; these are called *supernumerary bows.*

488. As the centre of the circle of which the rainbow is a part is in the continuation of a line drawn from the sun through the eye of the spectator, its position varies with that of the spectator, and its size with the degree of proximity of the sun to the horizon. Thus, if the sun be in the horizon the rainbow will be a semicircle; if higher, less than a semicircle; if about 42° high, the top of the primary bow will be just visible in the horizon; and if at greater heights, no rainbow will be formed on the sky. Rainbows have been sometimes seen from the tops of mountains forming complete circles when the sun was high and a shower of rain was falling in the plain below.

489. When the sun is reflected from the surface of still water *extraordinary bows* are sometimes formed. From the reflected image of the sun being in effect beneath the horizon, such bows are larger than a semicircle. The arrangement of the colours is the same as the primary bow; and when their summit happens to coincide with that of the secondary bow, a band of white light is formed at the place of union where they blend together.

490. *Lunar Rainbows.*—Rainbows are also produced by the light of the moon falling on a shower of raindrops in exactly the same way as solar rainbows. They are by no means of rare occurrence. Owing to the feeble light of the moon the bow is generally without colours; but when the sky is very clear and the moon at the full, the prismatic colours appear, but with subdued splendour.

491. Since rainbows in the morning are always seen in the west, they indicate the advance of the rain-cloud from the west at the time that it is clear and bright in the east; and since the fall of rain at a time of the day when the temperature should be rising is an additional evidence of increasing moisture, a morning rainbow is regarded as a prognostic of a change to wet stormy weather.

On the contrary, the conditions under which a rainbow can appear in the evening are, the passing of the rain-cloud to the east, and a clearing up in the west at the time of day when the temperature has begun to fall, thus further indicating a change from wet to dry weather. Hence the popular prognostic,—

> "A rainbow in the morning—
> Sailors take warning;
> A rainbow at night
> Is the sailor's delight."

492. *Coronas.*—The corona is an appearance of faintly-coloured rings encircling the moon when seen behind the light fleecy cloud of the cirro-cumulus. When the corona is perfect, the rings form several concentric circles, the blue prismatic colour being nearer the centre than the red. When of large dimensions it is called a *brough* in Scotland, and the ring has then generally a whitish nebulous appearance. The peculiar rings of the corona may be seen by looking at a light through a piece of glass upon which club-moss seed, which is very small, has been dusted; and the same appearance may be observed by looking at the gas-lamps of the streets through the window of a carriage on which moisture has been condensed.

493. Coronas can only be seen when the globules composing the cloud are all or nearly all of equal size; and the smaller the size of the globules the greater is the diameter of the corona. Hence the corona supplies a valuable prognostic. For when the diameter contracts round the moon, we know that the watery particles composing it are uniting into larger ones, which by-and-by will fall in rain; whereas if the corona be extending, the particles are growing less, thus indicating dryness.

494. Coronas are also very frequently formed round the sun; but to see them it is necessary to dim the strong light, by looking through smoked glass, or at his image reflected from still water.

495. *Glories of light,* sometimes called *anthelia,* because formed opposite the sun, are sometimes seen when the shadow of an observer is cast on fog, surrounding the head of his shadow with prismatic circles. On one occasion Scoresby saw four coloured concentric circles around his shadow, and he observed that the phenomenon was always seen in the polar regions whenever sunshine and fog occurred at the same time.

496. *Halos.*—Halos are circles of prismatic colours around the sun (figs. 48, 49, 50, and 51) or moon (figs. 52 and 53), but they are perfectly distinct from coronas, with which they should not be confounded. Halos are of comparatively rare occurrence; coronas

may be seen every time a light fleecy cloud comes between us and the sun or moon. The structure of halos, as seen from the figures,

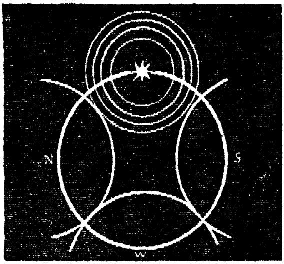


Fig. 48.

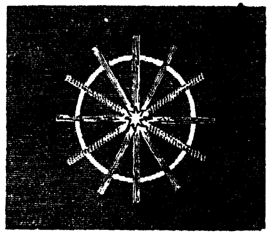


Fig. 49.

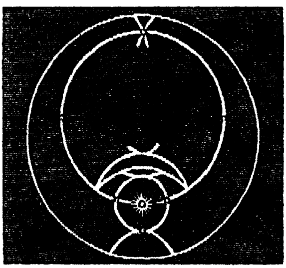


Fig. 50.

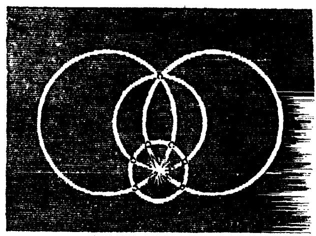


Fig. 51.

is often very complicated, circle cutting circle in the most re-

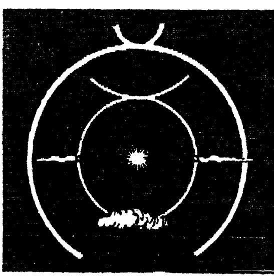


Fig. 52.

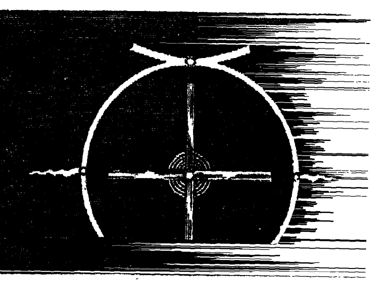


Fig. 53.

markable manner, and with mathematical exactness, the diameters of the circles being generally very large; but the structure of

the corona is simple, the circles concentric, the inner one small, varying from 2° to 4°, the diameter of the second circle being double that of the first, and of the third three times. In halos, the red prismatic colour is next the centre; in coronas, the blue. Halos are formed from the refraction and reflection of the rays of light by the minute snow-crystals of the cirrus cloud; while coronas arise from the interference of the rays passing on each side of the globules of vapour.

497. *Parhelia and Paraselena.*—At the points of intersection of the circles of the halo, images of the sun or moon generally appear from the light concentrated at these points, the images of the sun being called *parhelia* or *mock-suns,* and those of the moon *paraselenæ* or *mock-moons,* which also exhibit the prismatic colours of the halo.

498. Colours of Clouds.—The gorgeous aërial landscapes of red and golden-coloured clouds which fire the western sky at sunset, "the day's dying glory" of the poet, all admire. They are observed to be the accompaniment of cumulus clouds (the cloud of the day during fine weather), while in the act of dissolving as they sink slowly down into the lower and warmer parts of the atmosphere, consequently they disappear from the sky shortly after sunset. Such sunsets are therefore universally regarded as prognostics of fine weather.

499. Frequently small thin clouds appear high up in the eastern sky some time before sunrise, or when

> "The dappled dawn doth rise;"

and when the sun has risen they disappear. They are probably caused by the sun shining on and warming the upper layers of the atmosphere before it appears above the horizon; thus small ascending currents are formed, the vapour of which, as they ascend, is condensed in small clouds, or the cirro-cumulus. Their rounded definite forms show them to be produced in the same manner as the cumulus cloud—viz., by ascending currents forcing their way through colder strata. Their consistence is thin and vapoury, and their colour generally whitish or grey. They may thus be regarded as heralding the cumulus, and as sure prognostics of fine weather.

500. A green or yellowish-green tinted sky, on the other hand, is one of the surest prognostics of rain in summer, and snow in winter. An attentive consideration of the changing tints of the evening sky after stormy weather, supplies valuable help in forecasting the weather; for if the yellow tint becomes of a sickly-green, more rain and stormy weather may be expected; but if it

deepen into orange and red, the atmosphere is getting drier, and fine weather may be looked forward to.

501. Some years ago, Principal Forbes showed from experiments that high-pressure steam, while transparent, and *in the act of expansion*, readily absorbs the violet, blue, and part of the green rays, thus letting the yellow, orange, and red pass; and he suggested that coloration may be produced in a mixture of air and vapour, when the vapour is in the intermediate state referred to above. If this supposition be correct, we have some explanation of the gorgeous hues of sunset; for since the clouds are then in the act of dissolving, a considerable part of their substance is in the act of expansion from the vesicular into the invisible vaporous form; they are therefore in the very state most favourable for letting the yellow and red rays pass through. The morning clouds, on the other hand, are not in the act of dissolving, but of forming, at least till about sunrise; after which they rapidly melt away in the sun's heat. And it is remarkable that at this time—that is, when in the act of dissolution—they appear of an orange or reddish tinge, which, in contrast with the gorgeous colours of evening, is very faint, because they are dissolved in a much stronger and rapidly increasing light. Milton has accurately described it in 'L'Allegro'—

> "The great sun begins his state,
> Robed in flames, and amber light
> The clouds in thousand liveries dight."

But when a storm happens to be approaching from the west, and heavy-looking clouds, the *avant-couriers* of the storm, are gathering in the east at sunrise, part of the vapour passes into the invisible state as the sun's rays fall on the clouds, which thus appear of a red colour; and the colour is the deeper in proportion as the thickening clouds are darkening the sky. Hence, in the morning, when the sky is red and lowering, it is regarded as a prognostic of unsettled weather.

Meteors.

502. *Meteors and Shooting Stars* can scarcely with propriety be included among meteorological phenomena, since the whole of the facts known regarding them lead to their being classed with astronomical bodies. Of late years they have been carefully observed and their movements made the subject of scientific investigation; and attention has been forcibly drawn to their consideration by the magnificent star-shower of the night of the 13th

and 14th November last (1866), which had been accurately predicted beforehand. During a shower of meteors, if the lines of the tracks of the different meteors be projected on the sky, it is found that they meet nearly all in one point. This is the vanishing point in the perspective on which their tracks are projected, and points to that region in space over which the meteors are distributed. A number of these vanishing points have been determined. Olmstead first drew attention to this inquiry regarding the distribution in space of the meteoric matter, and showed that the great star-shower of November 1833 had its vanishing point in the constellation Leo. Professor Newton, America, has collected the records of the great November showers from the tenth century, from which there is evidence of eleven instances of their occurrence; and these records prove that they recur at regular intervals of thirty-three years and part of a day, the date of their occurrence having been from the 9th to the 14th November. In addition to the annual period in November, meteors also are frequently observed about the 11th of August; and, though not so general, at other times of the year.

503. These showers indicate the regions of space through which immense numbers of meteors are moving with planetary velocity; and when the earth in its motion round the sun travels through these spaces, it attracts to it many of these cosmical bodies, which, as they enter the atmosphere with a speed of about thirty miles a second, are set on fire by the mere rapidity of their flight, like the arrow shot by Acestes—

> "Chafed by the speed, it fired; and as it flew,
> A trail of following flames ascending drew."

The meteors move in an orbit inclined 7° to that of the earth. Mr Alexander Herschel has particularly studied this class of bodies, and from twenty well-observed cases, has determined their weight as varying from 30 grains to upwards of 7 lb.

504. Since they become luminous on entering the atmosphere, it is evident that careful observations made at different places would give an approximate solution to the problem of the height of the atmosphere. From such observations it is concluded that the earth's atmosphere is at least one hundred miles high, and that probably, though in an extremely attenuated form, it reaches to about two hundred miles. The extraordinary quantity of latent heat in air so attenuated, becomes sensible as the air is compressed before the meteor, and thus we have a satisfactory explanation of the swift ignition of all meteors as they traverse the atmosphere, and the rapid conversion of the smaller ones into

thin mist, which in some cases is seen floating in the sky for half an hour. Meteors enter the atmosphere bringing with them the temperature of the stellar spaces, which Sir John Herschel supposes to be $-239°$; and since their surfaces quickly become highly heated, an explosion soon takes place from the difference of the temperatures. Such explosions, however, do not always take place; thus the meteoric mass which fell at Dhurmsala, in India, on the 14th of July 1861, was first very hot, but it soon became so intensely cold that it could not be touched.

505. Speculation has gravely attempted to bring this interesting class of bodies within the legitimate domain of meteorology, by supposing that a shadow from the annular ring of meteors rotating round the sun, falls on the earth at certain seasons—viz., in February, May, August, and November—in consequence of which part of the sun's heat is cut off, and the temperature of the earth therefore falls. It is conclusive proof against this theory, that when the interruptions of temperature are particularly investigated, it is found that the date of their occurrence varies backwards and forwards to some extent from year to year; that the duration of their occurrence varies from three to six days, or sometimes longer; and that instead of appearing simultaneously at different places, they are propagated from place to place like other changes of temperature, thus pointing to a terrestrial instead of an astronomical origin.

Weather.

506. Weather is the condition of the air at any time as regards heat, moisture, wind, rain, cloud, and electricity; and a change of weather implies a change in one or more of these atmospheric elements. From the direct bearing which weather-changes have on human interests and pursuits, they have been closely observed from the earliest times, so that their approach might be predicted with some degree of confidence. The strong craving in the public mind for this knowledge is attested by the prognostics current in every language, which, amid much that is shrewd and of practical value, embody more that is vague, and not a little that is absurd. Any reference to Moore and other almanac-makers is unnecessary, except as testimonies to a widespread ignorance of even the most palpable elements of physical law, which is a disgrace to the educational system of the country. Nay, even when prognosticators of higher pretensions appear before the public with revelations, weeks or months beforehand, of fine or stormy weather

fraught with great advantage or incalculable disaster to the crops, it is curious to note how their predictions are laid hold of by the newspapers and scattered broadcast over the country. A strict examination of the records of the weather in the Greenwich Observatory has proved conclusively that predictions based on the moon's changes are equally delusive.

507. The truth is, no prediction of the weather can be made, at least in the British Islands, for more than three, or perhaps only two, days beforehand; and any attempt at a longer prediction is illusory. The principles laid down in the chapter on Storms show the possibility and mode of making real predictions. Thus, if from telegrams of the weather it appears that barometers are everywhere high over Europe, then no storm need be dreaded for two days at least. But if, on the following morning, barometers begin to fall in the west of Ireland, and easterly winds to blow over Great Britain and Norway, and south-easterly winds over France, it is likely that a storm, more or less severe, is approaching the British Islands. The indications ought now to be closely watched by the telegraph; and if the winds veer towards the south and west and increase in force, and barometers in Ireland fall rapidly, a great storm is portended, the approach of which should be telegraphed at once to the seaports threatened by it. But if, on the contrary, barometers fall slightly or cease to fall, and the winds do not increase in strength, the storm has either passed considerably to the north of the British Islands, or its approach is delayed; and no immediate warning is necessary. The collecting of this information by the telegraph is a work which, owing to the expense, Government alone can accomplish; and, from the important interests at stake, it is a duty they ought to discharge for the benefit of the seafaring population.

508. From the great value of weather telegrams to persons interested in shipping, the time cannot be far distant when each of our principal seaports will be in receipt of daily telegrams of the barometer and winds from places at some distance. Thus, if Leith was in possession of this information from Skuddesnaes in Norway, Archangel, Riga, Groningen, Brest, Valentia, and that place in Europe where for the time the barometer happens to be lowest, and was also warned by the central office in London of any storm which might appear to threaten it; then the general direction and force of the wind would be known from day to day over those seas chiefly traversed by ships belonging to Leith, and no storm could occur for which they would not be prepared at that port, as far as circumstances might permit. To persons who propose sailing for pleasure, or on business, such telegrams of the weather

would prove valuable, not only in giving warning of storms which are likely to cross the proposed route of sailing, but also in drawing attention to those storms which, though they may turn aside into neighbouring regions, are yet certain to disturb that part of the sea by the high swelling waves the winds raise and then roll before them to a great distance. Much may also be done by each person for himself by observing his barometer, the winds, and the face of the sky, especially the appearances of the cirrus cloud; but before his observations can be intelligently turned to account and made the most of, some knowledge of the general features of storms is indispensable.

509. But though no prediction of the weather, weeks or months beforehand, can be made with any pretension to trustworthiness, yet guesses or surmises may be formed which are not without value. All prediction based on solar or other astronomical causes, if not misleading, is useless ; and our only safe guides are averages based on terrestrial observations. Of this class may be mentioned the interruptions in the regular march of temperature in the course of the year. Thus cold weather often prevails about the 11th of April, "the borrowing days" (O. S.), and the second week of May, and warm weather about the middle of August and beginning of December; and these, with some other cold and warm periods, occur over a considerable part of the earth's surface. Hence, when at these times the weather begins to get warm or cold, a continuance of such weather may be expected for a few days. If, after an unusual prevalence of south-west wind, or the equatorial current, the polar current or north-east wind should set in, it is highly probable that easterly winds will prevail for some time; and if the season be winter, frost, and perhaps snow, may be looked for; but if summer, the weather will become dry, warm, and bracing. But suppose easterly winds have largely predominated in autumn, and south-westerly winds begin to prevail in the end of November or beginning of December, the weather is likely to continue exceptionably mild, with frequent storms of wind and rain, till about Christmas. This period occurs nearly every year, and its beginning is popularly known as St Martin's summer. On the same principle, if easterly winds preponderate largely above the average in spring, the summer is likely to be characterised by south-westerly winds, with much rain and moisture, and little sunshine; but if easterly winds nearly fail in spring, they are likely to prevail in summer, bringing in their train dry, warm, bracing weather, clear skies, and brilliant sunshine. This latter prognostic is entertained by several meteorologists of note; but a comparison of the weather of spring with that of the succeeding summer during

the last eleven years in Scotland shows, that while it holds good in the majority of cases, the number of times it fails are too many to entitle it to the claim of a trustworthy prognostic.

510. The *south-east* wind, when rightly understood, is a most valuable weather prognostic in Great Britain. There are two totally distinct kinds of south-east wind,—the one presaging stormy weather, and the other settled fine weather. The former has been just referred to in art. 507; its characteristics are moisture and warmth, and the sky clear down to the horizon, or streaked with cirrus clouds, and then covered with clouds bringing rain. The wind itself is caused by an in-draught towards the low barometer which accompanies a storm approaching from the west, and it ultimately veers to the south and west as the storm advances. The other south-east wind is accompanied with dry weather, a clear sky with haze near the horizon, and a high barometer still rising or stationary. It is the result of a higher atmospheric pressure descending over Russia and central Europe, and it does not veer to the south and west. Since this, our only really settled fine weather, is almost always a consequence of the polar current coming from the north of Russia and spreading itself over Europe, it will scarcely be necessary to point out the great value of daily telegrams of the barometer and winds from Archangel and Riga in giving the first intimation of its probable approach to spread sheets of ice over our ponds and lakes in winter, to dry the land in spring for the reception of seed, and to bring sunshine in summer and autumn for the ripening and ingathering of the fruits of the earth.

TABLE I.—FOR REDUCING BAROMETRIC OBSERVATIONS TO THE FREEZING-POINT (32° F.)

Temp. Fah.	English Inches.								Temp. Fah.
°	27	27.5	28	28.5	29	29.5	30	30.5	°
29	−.001	−.001	−.001	−.001	−.001	−.001	−.001	−.001	29
30	.004	.004	.004	.004	.004	.004	.004	.004	30
31	.006	.006	.006	.006	.007	.007	.007	.007	31
32	.008	.009	.009	.009	.009	.009	.009	.010	32
33	.011	.011	.011	.012	.012	.012	.012	.012	33
34	.013	.014	.014	.014	.014	.015	.015	.015	34
35	.016	.016	.016	.017	.017	.017	.018	.018	35
36	.018	.019	.019	.019	.020	.020	.020	.021	36
37	.021	.021	.021	.022	.022	.022	.023	.023	37
38	.023	.023	.024	.024	.025	.025	.026	.026	38
39	.025	.026	.026	.027	.027	.028	.028	.029	39
40	.028	.028	.029	.029	.030	.030	.031	.031	40
41	.030	.031	.031	.032	.033	.033	.034	.034	41
42	.033	.033	.034	.034	.035	.036	.036	.037	42
43	.035	.036	.036	.037	.038	.038	.089	.040	43
44	.037	.038	.039	.040	.040	.041	.042	.042	44
45	.040	.041	.041	.042	.043	.044	.044	.045	45
46	.042	.043	.044	.045	.045	.046	.047	.048	46
47	.045	.046	.046	.047	.048	.049	.050	.051	47
48	.047	.048	.049	.050	.051	.052	.052	.053	48
49	.050	.050	.051	.052	.053	.054	.055	.056	49
50	.052	.053	.054	.055	.056	.057	.058	.059	50
51	.054	.055	.056	.057	.058	.059	.060	.061	51
52	.057	.058	.059	.060	.061	.062	.063	.064	52
53	.059	.060	.061	.063	.064	.065	.066	.067	53
54	.062	.063	.064	.065	.066	.067	.068	.070	54
55	.064	.065	.066	.068	.069	.070	.071	.072	55
56	.066	.068	.069	.070	.071	.073	.074	.075	56
57	.069	.070	.071	.073	.074	.075	.076	.078	57
58	.071	.073	.074	.075	.077	.078	.079	.081	58
59	.074	.075	.076	.078	.079	.080	.082	.083	59
60	.076	.077	.079	.080	.082	.083	.085	.086	60
61	.078	.080	.081	.083	.084	.086	.087	.089	61
62	.081	.082	.084	.085	.087	.088	.090	.091	62
63	.083	.085	.086	.088	.089	.091	.093	.094	63
64	.086	.087	.089	.090	.092	.094	.065	.097	64
65	.088	.090	.091	.093	.095	.096	.098	.100	65
66	.090	.092	.094	.096	.097	.099	.101	.102	66
67	.093	.095	.096	.098	.100	.102	.103	.105	67
68	.095	.097	.099	.101	.102	.104	.106	.108	68
69	.098	.100	.101	.103	.105	.107	.109	.110	69
70	.100	.102	.104	.106	.108	.109	.111	.113	70
71	.102	.104	.106	.108	.110	.112	.114	.116	71
72	.105	.107	.109	.111	.113	.115	.117	.119	72
73	.107	.109	.111	.113	.115	.117	.119	.121	73
74	.110	.112	.114	.116	.118	.120	.122	.124	74
75	.112	.114	.116	.118	.120	.122	.125	.127	75
76	.114	.117	.119	.121	.123	.125	.127	.129	76
77	.117	.119	.121	.123	.126	.128	.130	.132	77
78	.119	.122	.124	.126	.128	.130	.133	.135	78
79	.122	.124	.126	.128	.131	.133	.135	.137	79
80	.124	.126	.129	.131	.133	.136	.138	.140	80
81	.126	.129	.131	.134	.136	.138	.141	.143	81
82	.129	.131	.134	.136	.138	.141	.143	.146	82
83	.131	.134	.136	.139	.141	.143	.146	.148	83
84	.134	.136	.139	.141	.144	.146	.149	.151	84
85	.136	.139	.141	.144	.146	.149	.151	.154	85
86	.138	.141	.144	.146	.149	.151	.154	.156	86
87	.141	.143	.146	.149	.151	.154	.157	.159	87
88	.143	.146	.149	.151	.154	.157	.159	.162	88
89	.146	.148	.151	.154	.156	.159	.162	.165	89
90	.148	.151	.153	.156	.159	.162	.164	.167	90

Table II.—For Converting Millimetres into English Inches and Decimals.

A millimetre equals 0.03937079 *English inch.*

Milli-metres.	Inches.	Milli-metres.	Inches.	Milli-metres.	Inches.	Milli-metres.	Inches	Milli-metres.	Inches.
661	26.024	687	27.048	713	28.071	739	29.095	765	30.119
662	26.063	688	27.087	714	28.111	740	29.134	766	30.158
663	26.103	689	27.126	715	28.150	741	29.174	767	30.197
664	26.142	690	27.166	716	28.189	742	29.213	768	30.237
665	26.182	691	27.205	717	28.229	743	29.252	769	30.276
666	26.221	692	27.245	718	28.268	744	29.292	770	30.316
667	26.260	693	27.284	719	28·308	745	29.331	771	30.355
668	26.300	694	27.323	720	28.347	746	29.371	772	30.394
669	26.339	695	27.363	721	28.386	747	29.410	773	30.434
670	26.378	696	27.402	722	28.426	748	29.449	774	30.473
671	26.418	697	27.441	723	28.465	749	29.489	775	30.512
672	26.457	698	27.481	724	28.504	750	29.528	776	30.552
673	26.497	699	27.520	725	28.544	751	29.567	777	30.591
674	26.536	700	27.560	726	28.583	752	29.607	778	30.630
675	26.575	701	27.599	727	28.623	753	29.646	779	30.670
676	26.615	702	27.638	728	28.662	754	29.686	780	30.709
677	26.654	703	27.678	729	28.701	755	29.725	781	30.749
678	26.693	704	27.717	730	28.741	756	29.764	782	30.788
679	26.733	705	27.756	731	28.780	757	29.804	783	30.827
680	26.772	706	27.796	732	28.819	758	29.843	784	30.867
681	26.812	707	27.835	733	28.859	759	29.882	785	30.906
682	26.851	708	27.875	734	28.898	760	29.922	786	30.945
683	26.890	709	27.914	735	28.938	761	29.961	787	30.985
684	26.930	710	27.953	736	28.977	762	30.001	788	31.024
685	26.969	711	27.993	737	29.016	763	30.040	789	31.064
686	27.008	712	28.032	738	29.056	764	30.079	790	31.103

Tenths of a Millimetre in the Decimal of an Inch.

0	1	2	3	4	5	6	7	8	9
0.000	0.004	0.008	0.012	0.016	0.020	0.024	0.028	0.031	0.035

TABLE III.—FOR REDUCING BAROMETRIC OBSERVATIONS TO THE LEVEL OF THE SEA; AND CONVERSELY, FOR THE DETERMINATION OF HEIGHTS BY THE BAROMETER.

Height above Sea-level in feet.	28 Inches.			29 Inches.			30 Inches.		
	32°	52°	72°	32°	52°	72°	32°	52°	72°
10	+.011	+.010	+.010	+.011	+.011	+.010	+.011	+.011	+.011
20	.022	.021	.020	.022	.021	.020	.023	.022	.021
30	.032	.031	.030	.033	.032	.031	.035	.033	.032
40	.043	.042	.040	.045	.044	.042	.046	.044	.042
50	.054	.052	.049	.056	.053	.051	.058	.055	.053
60	.064	.062	.059	.067	.064	.061	.069	.066	.063
70	.075	.072	.069	.078	.075	.071	.081	.077	.074
80	.086	.082	.079	.089	.085	.082	.092	.088	.084
90	.097	.093	.089	.100	.096	.092	.104	.099	.095
100	.107	.103	.099	.111	.107	.102	.115	.110	.106
150	.161	.154	.148	.167	.160	.153	.173	.165	.158
200	.215	.206	.197	.223	.213	.204	.230	.220	.211
250	.269	.257	.246	.278	.267	.255	.288	.276	.264
300	.322	.309	.296	.334	.320	.306	.345	.331	.317
350	.376	.360	.345	.390	.373	.357	.403	.386	.370
400	.440	.421	.403	.456	.436	.418	.461	.441	.422
450	.484	.463	.444	.501	.479	.459	.518	.496	.475
500	.537	.515	.493	.557	.533	.510	.576	.551	.528
550	.591	.566	.542	.612	.586	.561	.633	.606	.581
600	.645	.617	.591	.668	.639	.612	.691	.662	.634
650	.698	.669	.641	.723	.693	.664	.748	.717	.686
700	.752	.720	.690	.779	.746	.713	.806	.772	.739
750	.806	.772	.739	.835	.799	.765	.864	.827	.792
800	.860	.823	.788	.890	.853	.817	.921	.882	.845
850	.913	.875	.836	.946	.905	.866	.979	.937	.898
900	.967	.926	.887	1.000	.959	.919	1.036	.992	.950
950	1.021	.978	.936	1.057	1.012	.970	1.094	1.048	1.003
1000	1.074	1.029	.986	1.113	1.066	1.021	1.151	1.102	1.056
1050	1.128	1.080	1.035	1.169	1.119	1.047	1.208	1.158	1.109
1100	1.182	1.132	1.082	1.224	1.172	1.123	1.267	1.213	1.162
1150	1.236	1.183	1.133	1.280	1.226	1.174	1.322	1.268	1.214
1200	1.290	1.235	1.183	1.336	1.284	1.225	1.382	1.323	1.267
1300	1.397	1.338	1.281	1.447	1.385	1.327	1.497	1.433	1.373
1400	1.508	1.441	1.380	1.558	1.492	1.429	1.612	1.544	1.478
1500	1.612	1.544	1.478	1.670	1.599	1.531	1.727	1.654	1.584
1600	1.719	1.646	1.577	1.781	1.705	1.633	1.842	1.764	1.690
1700	1.827	1.749	1.672	1.892	1.812	1.731	1.957	1.874	1.795
1800	1.934	1.852	1.774	2.003	1.911	1.847	2.073	1.985	1.901
1900	2.042	1.955	1.873	2.115	2.017	1.940	2.188	2.095	2.006
2000	2.149	2.058	1.971	2.226	2.128	2.042	2.303	2.205	2.112

Table IV.—Comparison of the Centigrade Thermometer with Fahrenheit's and Reaumur's, giving the corresponding Values for each Degree, from +50° to —41° Centigrade.

Cent.	Fahr.	Reau.	Cent.	Fahr.	Reau.	Cent.	Fahr.	Reau.	Cent.	Fahr.	Reau.
°	°	°	°	°	°	°	°	°	°	°	°
50	122.0	40.0	27	80.6	21.6	4	39.2	3.2	—19	— 2.2	—15.2
49	120.2	39.2	26	78.8	20.8	3	37.4	2.4	—20	— 4.0	—16.0
48	118.4	38.4	25	77.0	20.0	2	35.6	1.6	—21	— 5.8	—16.8
47	116.6	37.6	24	75.2	19.2	1	33.8	0.8	—22	— 7.6	—17.6
46	114.8	36.8	23	73.4	18.4	0	32.0	0.0	—23	— 9.4	—18.4
45	113.0	36.0	22	71.6	17.6	— 1	30.2	— 0.8	—24	—11.2	—19.2
44	111.2	35.2	21	69.8	16.8	— 2	28.4	— 1.6	—25	—13.0	—20.0
43	109.4	34.4	20	68.0	16.0	— 3	26.6	— 2.4	—26	—14.8	—20.8
42	107.6	33.6	19	66.2	15.2	— 4	24.8	— 3.2	—27	—16.6	—21.6
41	105.8	32.8	18	64.4	14.4	— 5	23.0	— 4.0	—28	—18.4	—22.4
40	104.0	32.0	17	62.6	13.6	— 6	21.2	— 4.8	—29	—20.2	—23.2
39	102.2	31.2	16	60.8	12.8	— 7	19.4	— 5.6	—30	—22.0	—24.0
38	100.4	30.4	15	59.0	12.0	— 8	17.6	— 6.4	—31	—23.8	—24.8
37	98.6	29.6	14	57.2	11.2	— 9	15.8	— 7.2	—32	—25.6	—25.6
36	96.8	28.8	13	55.4	10.4	—10	14.0	— 8.0	—33	—27.4	—26.4
35	95.0	28.0	12	53.6	9.6	—11	12.2	— 8.8	—34	—29.2	—27.2
34	93.2	27.2	11	51.8	8.8	—12	10.4	— 9.6	—35	—31.0	—28.0
33	91.4	26.4	10	50.0	8.0	—13	8.6	—10.4	—36	—32.8	—28.8
32	89.6	25.6	9	48.2	7.2	—14	6.8	—11.2	—37	—34.6	—29.6
31	87.8	24.8	8	46.4	6.4	—15	5.0	—12.0	—38	—36.4	—30.4
30	86.0	24.0	7	44.6	5.6	—16	3.2	—12.8	—39	—38.2	—31.2
20	84.2	23.2	6	42.8	4.8	—17	1.4	—13.6	—40	—40.0	—32.0
28	82.4	22.4	5	41.0	4.0	—18	—0.4	—14.4	—41	—41.8	—32.8

Comparison of the Scales for each Tenth of a Degree.

Cent. . .	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Fahr. . .	0.18	0.36	0.54	0.72	0.9	1.08	1.26	1.44	1.62	1.8
Reau. . .	0.08	0.16	0.24	0.32	0.4	0.48	0.56	0.64	0.72	0.8
Fahr. . .	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Cent. . .	0.06	0.11	0.17	0.22	0.28	0.33	0.39	0.44	0.5	0.56
Reau. . .	0.04	0.09	0.13	0.18	0.22	0.27	0.31	0.36	0.4	0.44
Reau. . .	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Fahr. . .	0.22	0.45	0.67	0.9	1.12	1.35	1.57	1.80	2.02	2.25
Cent. . .	0.12	0.25	0.37	0.5	0.62	0.75	0.87	1.00	1.12	1.25

TABLE V.—SHOWING THE ELASTIC FORCE OF AQUEOUS VAPOUR, IN INCHES OF MERCURY, FROM 0° TO 80°, calculated from the Experiments of Regnault.

From Mr Glaisher's Hygrometric Tables.

The intermediate tenths of degrees may be easily interpolated.

Temp.	Force of vapour.	Temp.	Force of vapour	Temp.	Force of vapour.	Temp.	Force of vapour.	Temp.	Force of vapour.
°	Inch.	°	Inch.	°	Inch.	°	Inch.	°	Inch.
0	.044	29.5	.163	39.7	.244	47.3	.327	54.7	.428
1	.046	30.0	.167	40.0	.247	47.5	.329	55.0	.433
2	.048	30.5	.170	40.3	.250	47.7	.331	55.5	.441
3	.050	31.0	.174	40.5	.252	48.0	.335	56.0	.449
4	.052	31.5	.177	40.7	.254	48.3	.339	56.5	.457
5	.054	32.0	.181	41.0	.257	48.5	.342	57.0	.465
6	.057	32.5	.184	41.3	.260	48.7	.344	57.5	.473
7	.060	33.0	.188	41.5	.262	49.0	.348	58.0	.482
8	.062	33.5	.192	41.7	.264	49.3	.352	59.0	.500
9	.065	34.0	.196	42.0	.267	49.5	.355	60.0	.518
10	.068	34.5	.199	42.3	.270	49.7	.357	61.0	.537
11	.071	35.0	.204	42.5	.272	50.0	.361	62.0	.556
12	.074	35.3	.206	42.7	.274	50.3	.365	63.0	.576
13	.078	35.5	.208	43.0	.277	50.5	.367	64.0	.596
14	.082	35.7	.209	43.3	.280	50.7	.370	65.0	.617
15	.086	36.0	.212	43.5	.283	51.0	.374	66.0	.639
16	.090	36.3	.214	43.7	.285	51.3	.378	67.0	.661
17	.094	36.5	.216	44.0	.288	51.5	.381	68.0	.684
18	.098	36.7	.218	44.3	.292	51.7	.384	69.0	.708
19	.103	37.0	.220	44.5	.294	52.0	.388	70.0	.733
20	.108	37.3	.223	44.7	.296	52.3	.393	71.0	.759
21	.113	37.5	.225	45.0	.299	52.5	.396	72.0	.785
22	.118	37.7	.226	45.3	.303	52.7	.399	73.0	.812
23	.123	38.0	.229	45.5	.305	53.0	.403	74.0	.840
24	.129	38.3	.231	45.7	.307	53.3	.407	75.0	.868
25	.135	38.5	.233	46.0	.311	53.5	.410	76.0	.897
26	.141	38.7	.235	46.3	.315	53.7	.413	77.0	.927
27	.147	39.0	.238	46.5	.317	54.0	.418	78.0	.958
28	.153	39.3	.240	46.7	.319	54.3	.422	79.0	.990
29	.160	39.5	.242	47.0	.323	54.5	.425	80.0	1.023

TABLE VI.—FACTORS FOR MULTIPLYING THE EXCESS OF THE DRY-BULB THERMOMETER OVER THAT OF THE WET-BULB, TO FIND THE EXCESS OF THE TEMPERATURE OF THE AIR ABOVE THAT OF THE DEW-POINT.

From Mr Glaisher's Hygrometric Tables.

Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.	Dry-bulb Ther.	Factor.
°		°		°		°		°	
10	8.78	28	5.12	46	2.14	64	1.83	82	1.67
11	8.78	29	4.63	47	2.12	65	1.82	83	1.67
12	8.78	30	4.15	48	2.10	66	1.81	84	1.66
13	8.77	31	3.70	49	2.08	67	1.80	85	1.65
14	8.76	32	3.32	50	2.06	68	1.79	86	1.65
15	8.75	33	3.01	51	2.04	69	1.78	87	1.64
16	8.70	34	2.77	52	2.02	70	1.77	88	1.64
17	8.62	35	2.60	53	2.00	71	1.76	89	1.63
18	8.50	36	2.50	54	1.98	72	1.75	90	1.63
19	8.34	37	2.42	55	1.96	73	1.74	91	1.62
20	8.14	38	2.36	56	1.94	74	1.73	92	1.62
21	7.88	39	2.32	57	1.92	75	1.72	93	1.61
22	7.60	40	2.29	58	1.90	76	1.71	94	1.60
23	7.28	41	2.26	59	1.89	77	1.70	95	1.60
24	6.92	42	2.23	60	1.88	78	1.69	96	1.59
25	6.53	43	2.20	61	1.87	79	1.69	97	1.59
26	6.08	44	2.18	62	1.86	80	1.68	98	1.58
27	5.61	45	2.16	63	1.85	81	1.68	99	1.58
								100	1.57

TABLE VII.—FOR COMPARING THE PRESSURE AND THE VELOCITY OF THE WIND. Calculated from the Formulæ, $V^2 \times .005 = P$; and $\sqrt{200 \times P} = V$.

From Instructions for taking Meteorological Observations, by Colonel Sir Henry James, R.E., F.R.S., &c.

Oz. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.	lb. per square foot.	Miles per hour.
0.25	1.77	1.	14.14	4.50	30.00	11	46.90	24	69.28
0.50	2.50	1.25	15.81	5.	31.62	12	48.99	26	72.11
0.75	3.06	1.50	17.32	5.50	33.17	13	50.99	28	74.83
1.	3.54	1.75	18.71	6.	34.64	14	52.92	30	77.46
2.	5.00	2.	20.00	6.50	36.06	15	54.77	32	80.00
3.	6.12	2.25	21.21	7.	37.42	16	56.57	34	82.46
4.	7.07	2.50	22.36	7.50	38.73	17	58.31	36	84.85
5.	7.90	2.75	23.45	8.	40.00	18	60.00	38	87.18
6.	8.66	3.	24.49	8.50	41.23	19	61.64	40	89.44
8.	10.00	3.25	25.50	9.	42.43	20	63.24	42	91.65
10.	11.18	3.50	26.46	9.50	43.59	21	64.81	45	94.87
12.	12.25	3.70	27.39	10.	44.72	22	66.33	48	97.98
14.	13.23	4.	28.28	10.50	45.82	23	67.82	50	100.00

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